Secure Quantum Communications

A protocol for secure quantum communications has been demonstrated over a record-breaking distance of 404 km. [16]

Randomness is vital for computer security, making possible secure encryption that allows people to communicate secretly even if an adversary sees all coded messages. Surprisingly, it even allows security to be maintained if the adversary also knows the key used to the encode the messages. [15]

Researchers at the University of Rochester have moved beyond the theoretical in demonstrating that an unbreakable encrypted message can be sent with a key that's far shorter than the message—the first time that has ever been done. [14]

Quantum physicists have long thought it possible to send a perfectly secure message using a key that is shorter than the message itself. Now they've done it. [13]

What once took months by some of the world's leading scientists can now be done in seconds by undergraduate students thanks to software developed at the University of Waterloo's Institute for Quantum Computing, paving the way for fast, secure quantum communication. [12]

The artificial intelligence system's ability to set itself up quickly every morning and compensate for any overnight fluctuations would make this fragile technology much more useful for field measurements, said co-lead researcher Dr Michael Hush from UNSW ADFA. [11]

Quantum physicist Mario Krenn and his colleagues in the group of Anton Zeilinger from the Faculty of Physics at the University of Vienna and the Austrian Academy of Sciences have developed an algorithm which designs new useful quantum experiments. As the computer does not rely on human intuition, it finds novel unfamiliar solutions. [10]

Researchers at the University of Chicago's Institute for Molecular Engineering and the University of Konstanz have demonstrated the ability to generate a quantum logic operation, or rotation of the qubit, that - surprisingly—is intrinsically resilient to noise as well as to variations in the strength or duration of the control. Their achievement is based on a geometric concept known as the Berry phase and is implemented through entirely optical means within a single electronic spin in diamond. [9]

New research demonstrates that particles at the quantum level can in fact be seen as behaving something like billiard balls rolling along a table, and not *merely as the probabilistic smears that the standard interpretation of quantum mechanics suggests. But there's a catch - the tracks the particles follow do not always behave as one would expect from "realistic" trajectories, but often in a fashion that has been termed "surrealistic." [8]*

Quantum entanglement—which occurs when two or more particles are correlated in such a way that they can influence each other even across large distances—is not an all-or-nothing phenomenon, but occurs in various degrees. The more a quantum state is entangled with its partner, the better the states will perform in quantum information applications. Unfortunately, quantifying entanglement is a difficult process involving complex optimization problems that give even physicists headaches. [7]

A trio of physicists in Europe has come up with an idea that they believe would allow a person to actually witness entanglement. Valentina Caprara Vivoli, with the University of Geneva, Pavel Sekatski, with the University of Innsbruck and Nicolas Sangouard, with the University of Basel, have together written a paper describing a scenario where a human subject would be able to witness an instance of entanglement—they have uploaded it to the arXiv server for review by others. [6]

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.

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Author: George Rajna

Preface

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. In a new proposed experiment in this area, two toaster-sized "nanosatellites" carrying entangled condensates orbit around the Earth, until one of them moves to a different orbit with different gravitational field strength. As a result of the change in gravity, the entanglement between the condensates is predicted to degrade by up to 20%. Experimentally testing the proposal may be possible in the near future. [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.

Synopsis: Quantum Cryptography Goes a Long Way

Encryption is critical in many aspects of modern life, such as the millions of credit card transactions that occur every day. However, perfectly secure communication can only be achieved using the strong correlations, or entanglement, between quantum objects. Now, Jian-Wei Pan at the University of Science and Technology of China and his colleagues have experimentally shown that a secure quantum protocol known as measurement-device-independent quantum key distribution (MDIQKD) can be implemented over a distance of 404 km. The result breaks the previous MDIQKD record by over a factor of 2 and paves the way for secure quantum communications between distant cities.

MDIQKD—a protocol proposed in 2012—functions even when it uses photon detectors that are not ideal and have, for example, low detection efficiencies. It can also overcome security loopholes of quantum communication schemes by sending out decoy pulses of light to detect eavesdropping attacks. Pan and his team sent pulses of infrared photons through optical fibers with lengths between 102 and 404 km and optimized the MDIQKD scheme by tuning several parameters, such as the average number of photons per pulse. The protocol was found to be secure up to the longest distance. For each length, the researchers also determined the maximum speed by which cryptographic keys could be securely distributed. Compared with earlier experiments, they demonstrated a 500-fold increase in speed, reaching a key-distribution rate that would be sufficient to ensure encrypted voice transmission by telephone.

This research is published in Physical Review Letters. [16]

How random is your randomness, and why does it matter?

Randomness is powerful. Think about a presidential poll: A random sample of just 400 people in the United States can accurately estimate Clinton's and Trump's support to within 5 percent (with 95 percent certainty), despite the U.S. population exceeding 300 million. That's just one of many uses.

Randomness is vital for computer security, making possible secure encryption that allows people to communicate secretly even if an adversary sees all coded messages. Surprisingly, it even allows security to be maintained if the adversary also knows the key used to the encode the messages.

Often random numbers can be used to speed up algorithms. For example, the fastest way we know to test whether a particular number is prime involves choosing random numbers. That can be helpful in math, computer science and cryptography, among other disciplines.

Random numbers are also crucial to simulating very complex systems. When dealing with the climate or the economy, for example, so many factors interact in so many ways that the equations involve millions of variables. Today's computers are not powerful enough to handle all these unknowns. Modeling this complexity with random numbers simplifies the calculations, and still results in accurate simulations.

But it turns out some – even most – computer-generated "random" numbers aren't actually random. They can follow subtle patterns that can be observed over long periods of time, or over many instances of generating random numbers. For example, a simple random number generator could be built by timing the intervals between a user's keystrokes. But the results would not really be random, because there are correlations and patterns in these timings, especially when looking at a large number of them.

Using this sort of output – numbers that appear at first glance to be unrelated but which really follow a hidden pattern – can weaken polls' accuracy and communication secrecy, and render those simulations useless. How can we obtain high-quality randomness, and what does this even mean?

Randomness quality

To be most effective, we want numbers that are very close to random. Suppose a pollster wants to pick a random congressional district. As there are 435 districts, each district should have one chance in 435 of being picked. No district should be significantly more or less likely to be chosen.

Low-quality randomness is an even bigger concern for computer security. Hackers often exploit situations where a supposedly random string isn't all that random, like when an encryption key is generated with keystroke intervals.

It turns out to be very hard for computers to generate truly random numbers, because computers are just machines that follow fixed instructions. One approach has been to use a physical phenomenon a computer can monitor, such as radioactive decay of a material or atmospheric noise. These are intrinsically unpredictable and therefore hard for a potential attacker to guess. However, these methods are typically too slow to supply enough random numbers for all the needs computers and people have.

There are other, more easily accessible sources of near-randomness, such as those keystroke intervals or monitoring computer processors' activity. However, these produce random numbers that do follow some patterns, and at best contain only some amount of uncertainty. These are low-quality random sources. They're not very useful on their own.

What we need is called a randomness extractor: an algorithm that takes as input two (or more) independent, low-quality random sources and outputs a truly random string (or a string extremely close to random).

Constructing a randomness extractor

Mathematically, it is impossible to extract randomness from just one low-quality source. A clever (but by now standard) argument from probability shows that it's possible to create a two-source extractor algorithm to generate a random number. But that proof doesn't tell us how to make one, nor guarantee that an efficient algorithm exists.

Until our recent work, the only known efficient two-source extractors required that at least one of the random sources actually had moderately high quality. We recently developed an efficient two-source extractor algorithm that works even if both sources have very low quality.

Our algorithm for the two-source extractor has two parts. The first part uses a cryptographic method called a "nonmalleable extractor" to convert the two independent sources into one series of coin flips. This allows us to reduce the two-source extractor problem to solving the a quite different problem.

Suppose a group of people want to collectively make an unbiased random choice, say among two possible choices. The catch is that some unknown subgroup of these people have their heart set on one result or the other, and want to influence the decision to go their way. How can we prevent this from happening, and ensure the ultimate result is as random as possible?

The simplest method is to just flip a coin, right? But then the person who does the flipping will just call out the result he wants. If we have everyone flip a coin, the dishonest players can cheat by waiting until the honest players announce their coin flips.

A middling solution is to let everyone flip a coin, and go with the outcome of a majority of coin flippers. This is effective if the number of cheaters is not too large; among the honest players, the number of heads is likely to differ from the number of tails by a significant amount. If the number of cheaters is smaller, then they won't be able to affect the outcome.

Protecting against cheaters

We constructed an algorithm, called a "resilient function," that tolerates a much larger number of cheaters. It depends on more than just the numbers of heads and tails. A building block of our function is called the "tribes function," which we can explain as follows.

Suppose there are 44 people involved in collectively flipping a coin, some of whom may be cheaters. To make the collective coin flip close to fair, divide them into 11 subgroups of four people each. Each subgroup will call out "heads" if all of its members flip heads; otherwise it will say "tails." The tribes function outputs "heads" if any subgroup says "heads;" otherwise it outputs "tails."

The tribes function works well if there is just one cheater. This is because if some other member of the cheater's subgroup flips tails, then the cheater's coin flip doesn't affect the outcome. However, it works poorly if there are four cheaters, and if those players all belong to the same subgroup. For then all of them could output "heads," and force the tribes function to output "heads."

To handle many cheaters, we build upon work of Miklos Ajtai and Nati Linial and use many different divisions into subgroups. This gives many different tribes functions. We then output "heads" if all these tribe functions output "heads"; otherwise we output "tails." Even a large number of cheaters is unlikely to be able to control the output, ensuring the result is, in fact, very random.

Our extractor outputs just one almost random bit – "heads" or "tails." Shortly afterwards Xin Li showed how to use our algorithm to output many bits. While we gave an exponential improvement, other researchers have further improved our work, and we are now very close to optimal.

Our finding is truly just one piece of a many-faceted puzzle. It also advances an important field in the mathematical community, called Ramsey theory, which seeks to find structure even in random-looking objects. [15]

The enigma machine takes a quantum leap

Researchers at the University of Rochester have moved beyond the theoretical in demonstrating that an unbreakable encrypted message can be sent with a key that's far shorter than the message—the first time that has ever been done.

Until now, unbreakable encrypted messages were transmitted via a system envisioned by American mathematician Claude Shannon, considered the "father of information theory." Shannon combined his knowledge of algebra and electrical circuitry to come up with a binary system of transmitting messages that are secure, under three conditions: the key is random, used only once, and is at least as long as the message itself.

The findings by Daniel Lum, a graduate student in physics, and John Howell, a professor of physics, have been published in the journal Physical Review A.

"Daniel's research amounts to an important step forward, not just for encryption, but for the field of quantum data locking," said Howell.

Quantum data locking is a method of encryption advanced by Seth Lloyd, a professor of quantum information at Massachusetts Institute of Technology, that uses photons—the smallest particles associated with light—to carry a message. Quantum data locking was thought to have limitations for securely encrypting messages, but Lloyd figured out how to make additional assumptions—namely those involving the boundary between light and matter—to make it a more secure method of sending data. While a binary system allows for only an on or off position with each bit of information, photon waves can be altered in many more ways: the angle of tilt can be changed, the wavelength can be made longer or shorter, and the size of the amplitude can be modified. Since a photon has more variables—and there are fundamental uncertainties when it comes to quantum measurements—the quantum key for encrypting and deciphering a message can be shorter that the message itself.

Lloyd's system remained theoretical until this year, when Lum and his team developed a device—a quantum enigma machine—that would put the theory into practice. The device takes its name from the encryption machine used by Germany during World War II, which employed a coding method that the British and Polish intelligence agencies were secretly able to crack.

Let's assume that Alice wants to send an encrypted message to Bob. She uses the machine to generate photons that travel through free space and into a spatial light modulator (SLM) that alters the properties of the individual photons (e.g. amplitude, tilt) to properly encode the message into flat but tilted wavefronts that can be focused to unique points dictated by the tilt. But the SLM does one more thing: it distorts the shapes of the photons into random patterns, such that the wavefront is no longer flat which means it no longer has a well-defined focus. Alice and Bob both know the keys which identify the implemented scrambling operations, so Bob is able to use his own SLM to flatten the wavefront, re-focus the photons, and translate the altered properties into the distinct elements of the message.

Along with modifying the shape of the photons, Lum and the team made use of the uncertainty principle, which states that the more we know about one property of a particle, the less we know about another of its properties. Because of that, the researchers were able to securely lock in six bits of classical information using only one bit of an encryption key—an operation called data locking.

"While our device is not 100 percent secure, due to photon loss," said Lum, "it does show that data locking in message encryption is far more than a theory."

The ultimate goal of the quantum enigma machine is to prevent a third party—for example, someone named Eve—from intercepting and deciphering the message.

A crucial principle of quantum theory is that the mere act of measuring a quantum system changes the system. As a result, Eve has only one shot at obtaining and translating the encrypted message—something that is virtually impossible, given the nearly limitless number of patterns that exist for each photon.

The paper by Lum and Howell was one of two papers published simultaneously on the same topic. The other paper, "Quantum data locking," was from a team led by Chinese physicist Jian-Wei Pan.

"It's highly unlikely that our free-space implementation will be useful through atmospheric conditions," said Lum. "Instead, we have identified the use of optic fiber as a more practical route for data locking, a path Pan's group actually started with. Regardless, the field is still in its infancy with a great deal more research needed." [14]

First Experimental Demonstration of a Quantum Enigma Machine

One of the great unsung heroes of 20th century science was a mathematician and engineer at the famous Bell Laboratories in New Jersey called Claude Shannon.

During the 1940s, '50s and '60s, Shannon laid the mathematical foundations for modern communications and computing while building some of the first intelligent machines.

Along the way, he also made a major contribution to the theory of cryptography with a paper entitled Communication Theory of Secrecy Systems, published in 1949.

In it, he proved it possible to send a perfectly secure message provided that the encryption key is entirely random and used only once. Shannon's work is the mathematical proof that the one-time pad is a truly unbreakable form of encryption. A critical condition is that the encryption key must be at least as long as the message itself.

The first quantum enigma machine.

Shannon's work assumes that the message is sent using conventional forms of transmission. But in the last 10 years, quantum physicists have shown that it is possible to do better if the message is encrypted using quantum rules. In particular, they have shown that in the quantum world, a secure message can be sent with a key that is significantly shorter than the message itself. At least in theory.

Researchers have christened this device a "quantum enigma machine," after the Nazi encryption device that codebreakers led by Alan Turing cracked during the Second World War. But the device has been entirely theoretical.

Until now. Today, Daniel Lum at the University of Rochester in New York State and a few pals unveil an actual working quantum enigma machine for the first time.

Their proof-of-principle device is capable of sending perfectly secure messages using a key that is shorter than the message itself.

A one-time pad works by adding a random number to each digit in a message. That makes the message indistinguishable from a randomness. It can only be read by subtracting the same random numbers to produce the original message.

The secrecy depends on the transmitter and receiver being the only people with the list of random numbers. And of course this list must be longer than the message itself.

The quantum version of this process works by encoding information in a quantum object such as a photon and then altering the state of the photon with a random operation. The information can only be retrieved by reversing the random operation. So as long as only the transmitter and receiver know the sequence of random operations—the quantum key—and that this key is used only once, the message is perfectly secure.

However, quantum theorists have shown that the quantum key can be exponentially shorter than the message itself.

Now Lum and co have built a transmitter and receiver that exploits this mechanism. Their device consists of a photon gun that fires single photons through a kind of mask called a spatial light modulator which superimposes information onto the photon's wavefront. If this modulator consists of an 8 x 8 array, it can encode 64 bits of information. At the same time, the spatial light modulator adds a random signal to the information it transmits.

The important point is that all the information encoded on the photon is randomized by a random signal. So the sequence of random signals used for encryption can be significantly shorter than the message itself.

That allows an important twist. Because the message is shorter than the key, it is also possible to send a new key for encoding the next message. In this way, the message and the new key are sent at the same time and both are kept entirely secret.

The receiver detects each photon using a light sensitive array that can pick out the pattern superimposed on the photon. It then subtracts the random signal leaving the original message.

Lum and co have done exactly this. "We demonstrated the phenomenon with a proof-of-principle experiment to lock 6 bits per photon while using less than 6 bits per photon of secret key," says the team. In other words, these guys have built the first proof-of-principle quantum enigma machine.

That's an interesting result that has immediate application. Physicists already use quantum mechanics to send perfectly secure messages using a technique called quantum key distribution. The techniques for doing this are becoming increasingly advanced. Indeed, there are already commercial versions of this kind quantum encryption on the market.

Lum and co say that the technology and techniques developed for quantum key distribution can be immediately applied to building quantum enigma machines. So there's no reason why the technique cannot be commercialized in the near future. Shannon would surely be impressed. [13]

Computing a secret, unbreakable key

Researchers at the Institute for Quantum Computing (IQC) at the University of Waterloo developed the first available software to evaluate the security of any protocol for Quantum Key Distribution (QKD).

QKD allows two parties, Alice and Bob, to establish a shared secret key by exchanging photons. Photons behave according to the laws of quantum mechanics, and the laws state that you cannot measure a quantum object without disturbing it. So if an eavesdropper, Eve, intercepts and measures the photons, she will cause a disturbance that is detectable by Alice and Bob. On the other hand, if there is no disturbance, Alice and Bob can guarantee the security of their shared key.

In practice, loss and noise in an implementation always leads to some disturbance, but a small amount of disturbance implies a small amount of information about the key is available to Eve. Characterizing this amount of information allows Alice and Bob to remove it from Eve at the cost of the length of the resulting final key.

The main theoretical problem in QKD is how to calculate the allowed length of this final secret key for any given protocol and the experimentally observed disturbance.

A mathematical approach was still needed to perform this difficult calculation. The researchers opted to take a numerical approach, and for practical reasons they transformed the key rate calculation to the dual optimization problem.

"We wanted to develop a program that would be fast and user-friendly. It also needs to work for any protocol," said Patrick Coles, an IQC postdoctoral fellow. "The dual optimization problem dramatically reduced the number of parameters and the computer does all the work."

The paper, Numerical approach for unstructured quantum key distribution, published in Nature Communications today presented three findings. First, the researchers tested the software against previous results for known studied protocols. Their results were in perfect agreement. They then studied protocols that had never been studied before. Finally, they developed a framework to inform users how to enter the data using a new protocol into the software.

"The exploration of QKD protocols so far concentrated on protocols that allowed tricks to perform the security analysis. The work by our group now frees us to explore protocols that are adapted to the technological capabilities" noted Norbert Lütkenhaus, a professor with IQC and the Department of Physics and Astronomy at the University of Waterloo. [12]

Physicists are putting themselves out of a job, using artificial intelligence to run a complex experiment

The experiment, developed by physicists from The Australian National University (ANU) and UNSW ADFA, created an extremely cold gas trapped in a laser beam, known as a Bose-Einstein condensate, replicating the experiment that won the 2001 Nobel Prize.

"I didn't expect the machine could learn to do the experiment itself, from scratch, in under an hour," said co-lead researcher Paul Wigley from the ANU Research School of Physics and Engineering.

"A simple computer program would have taken longer than the age of the Universe to run through all the combinations and work this out."

Bose-Einstein condensates are some of the coldest places in the Universe, far colder than outer space, typically less than a billionth of a degree above absolute zero.

They could be used for mineral exploration or navigation systems as they are extremely sensitive to external disturbances, which allows them to make very precise measurements such as tiny changes in the Earth's magnetic field or gravity.

The artificial intelligence system's ability to set itself up quickly every morning and compensate for any overnight fluctuations would make this fragile technology much more useful for field measurements, said co-lead researcher Dr Michael Hush from UNSW ADFA.

"You could make a working device to measure gravity that you could take in the back of a car, and the artificial intelligence would recalibrate and fix itself no matter what," he said.

"It's cheaper than taking a physicist everywhere with you."

The team cooled the gas to around 1 microkelvin, and then handed control of the three laser beams over to the artificial intelligence to cool the trapped gas down to nanokelvin.

Researchers were surprised by the methods the system came up with to ramp down the power of the lasers.

"It did things a person wouldn't guess, such as changing one laser's power up and down, and compensating with another," said Mr Wigley.

"It may be able to come up with complicated ways humans haven't thought of to get experiments colder and make measurements more precise.

The new technique will lead to bigger and better experiments, said Dr Hush.

"Next we plan to employ the artificial intelligence to build an even larger Bose-Einstein condensate faster than we've seen ever before," he said.

The research is published in the Nature group journal Scientific Reports. [11]

Quantum experiments designed by machines

The idea was developed when the physicists wanted to create new quantum states in the laboratory, but were unable to conceive of methods to do so. "After many unsuccessful attempts to come up with an experimental implementation, we came to the conclusion that our intuition about these phenomena seems to be wrong. We realized that in the end we were just trying random arrangements of quantum building blocks. And that is what a computer can do as well - but thousands of times faster", explains Mario Krenn, PhD student in Anton Zeilinger's group and first author research.

After a few hours of calculation, their algorithm - which they call Melvin - found the recipe to the question they were unable to solve, and its structure surprised them. Zeilinger says: "Suppose I want build an experiment realizing a specific quantum state I am interested in. Then humans intuitively consider setups reflecting the symmetries of the state. Yet Melvin found out that the most simple realization can be asymmetric and therefore counterintuitive. A human would probably never come up with that solution."

The physicists applied the idea to several other questions and got dozens of new and surprising answers. "The solutions are difficult to understand, but we were able to extract some new experimental tricks we have not thought of before. Some of these computer-designed experiments are being built at the moment in our laboratories", says Krenn.

Melvin not only tries random arrangements of experimental components, but also learns from previous successful attempts, which significantly speeds up the discovery rate for more complex solutions. In the future, the authors want to apply their algorithm to even more general questions in quantum physics, and hope it helps to investigate new phenomena in laboratories. [10]

Moving electrons around loops with light: A quantum device based on geometry

Researchers at the University of Chicago's Institute for Molecular Engineering and the University of Konstanz have demonstrated the ability to generate a quantum logic operation, or rotation of the qubit, that - surprisingly—is intrinsically resilient to noise as well as to variations in the strength or duration of the control. Their achievement is based on a geometric concept known as the Berry phase and is implemented through entirely optical means within a single electronic spin in diamond.

Their findings were published online Feb. 15, 2016, in Nature Photonics and will appear in the March print issue. "We tend to view quantum operations as very fragile and susceptible to noise, especially when compared to conventional electronics," remarked David Awschalom, the Liew Family Professor of Molecular Engineering and senior scientist at Argonne National Laboratory, who led the research. "In contrast, our approach shows incredible resilience to external influences and fulfills a key requirement for any practical quantum technology."

Quantum geometry

When a quantum mechanical object, such as an electron, is cycled along some loop, it retains a memory of the path that it travelled, the Berry phase. To better understand this concept, the Foucault pendulum, a common staple of science museums helps to give some intuition. A pendulum, like those in a grandfather clock, typically oscillates back and forth within a fixed plane. However, a Foucault pendulum oscillates along a plane that gradually rotates over the course of a day due to Earth's rotation, and in turn knocks over a series of pins encircling the pendulum.

The number of knocked-over pins is a direct measure of the total angular shift of the pendulum's oscillation plane, its acquired geometric phase. Essentially, this shift is directly related to the location of the pendulum on Earth's surface as the rotation of Earth transports the pendulum along a specific closed path, its circle of latitude. While this angular shift depends on the particular path traveled, Awschalom said, it remarkably does not depend on the rotational speed of Earth or the oscillation frequency of the pendulum.

"Likewise, the Berry phase is a similar path-dependent rotation of the internal state of a quantum system, and it shows promise in quantum information processing as a robust means to manipulate qubit states," he said.

A light touch

In this experiment, the researchers manipulated the Berry phase of a quantum state within a nitrogen-vacancy (NV) center, an atomic-scale defect in diamond. Over the past decade and a half, its electronic spin state has garnered great interest as a potential qubit. In their experiments, the team members developed a method with which to draw paths for this defect's spin by varying the applied laser light. To demonstrate Berry phase, they traced loops similar to that of a tangerine slice within the quantum space of all of the potential combinations of spin states.

"Essentially, the area of the tangerine slice's peel that we drew dictated the amount of Berry phase that we were able to accumulate," said Christopher Yale, a postdoctoral scholar in Awschalom's laboratory, and one of the co-lead authors of the project.

This approach using laser light to fully control the path of the electronic spin is in contrast to more common techniques that control the NV center spin, through the application of microwave fields. Such an approach may one day be useful in developing photonic networks of these defects, linked and controlled entirely by light, as a way to both process and transmit quantum information.

A noisy path

A key feature of Berry phase that makes it a robust quantum logic operation is its resilience to noise sources. To test the robustness of their Berry phase operations, the researchers intentionally added noise to the laser light controlling the path. As a result, the spin state would travel along its intended path in an erratic fashion.

However, as long as the total area of the path remained the same, so did the Berry phase that they measured.

"In particular, we found the Berry phase to be insensitive to fluctuations in the intensity of the laser. Noise like this is normally a bane for quantum control," said Brian Zhou, a postdoctoral scholar in the group, and co-lead author.

"Imagine you're hiking along the shore of a lake, and even though you continually leave the path to go take pictures, you eventually finish hiking around the lake," said F. Joseph Heremans, co-lead author, and now a staff scientist at Argonne National Laboratory. "You've still hiked the entire loop regardless of the bizarre path you took, and so the area enclosed remains virtually the same."

These optically controlled Berry phases within diamond suggest a route toward robust and fault-tolerant quantum information processing, noted Guido Burkard, professor of physics at the University of Konstanz and theory collaborator on the project.

"Though its technological applications are still nascent, Berry phases have a rich underlying mathematical framework that makes them a fascinating area of study," Burkard said. [9]

Researchers demonstrate 'quantum surrealism'

In a new version of an old experiment, CIFAR Senior Fellow Aephraim Steinberg (University of Toronto) and colleagues tracked the trajectories of photons as the particles traced a path through one of two slits and onto a screen. But the researchers went further, and observed the "nonlocal" influence of another photon that the first photon had been entangled with.

The results counter a long-standing criticism of an interpretation of quantum mechanics called the De Broglie-Bohm theory. Detractors of this interpretation had faulted it for failing to explain the behaviour of entangled photons realistically. For Steinberg, the results are important because they give us a way of visualizing quantum mechanics that's just as valid as the standard interpretation, and perhaps more intuitive.

"I'm less interested in focusing on the philosophical question of what's 'really' out there. I think the fruitful question is more down to earth. Rather than thinking about different metaphysical interpretations, I would phrase it in terms of having different pictures. Different pictures can be useful. They can help shape better intuitions."

At stake is what is "really" happening at the quantum level. The uncertainty principle tells us that we can never know both a particle's position and momentum with complete certainty. And when we do interact with a quantum system, for instance by measuring it, we disturb the system. So if we fire a photon at a screen and want to know where it will hit, we'll never know for sure exactly where it will hit or what path it will take to get there.

The standard interpretation of quantum mechanics holds that this uncertainty means that there is no "real" trajectory between the light source and the screen. The best we can do is to calculate a "wave function" that shows the odds of the photon being in any one place at any time, but won't tell us where it is until we make a measurement.

Yet another interpretation, called the De Broglie-Bohm theory, says that the photons do have real trajectories that are guided by a "pilot wave" that accompanies the particle. The wave is still probabilistic, but the particle takes a real trajectory from source to target. It doesn't simply "collapse" into a particular location once it's measured.

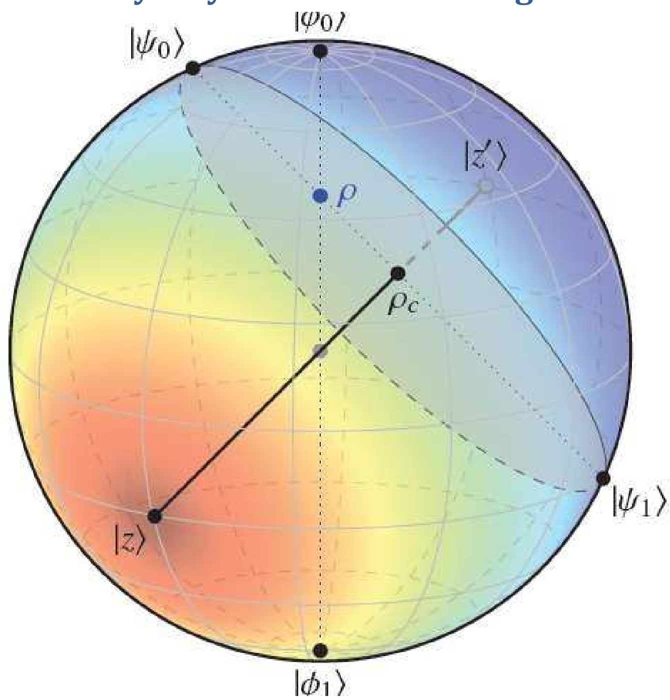
In 2011 Steinberg and his colleagues showed that they could follow trajectories for photons by subjecting many identical particles to measurements so weak that the particles were barely disturbed, and then averaging out the information. This method showed trajectories that looked similar to classical ones - say, those of balls flying through the air.

But critics had pointed out a problem with this viewpoint. Quantum mechanics also tells us that two particles can be entangled, so that a measurement of one particle affects the other. The critics complained that in some cases, a measurement of one particle would lead to an incorrect prediction of the trajectory of the entangled particle. They coined the term "surreal trajectories" to describe them.

In the most recent experiment, Steinberg and colleagues showed that the surrealism was a consequence of non-locality - the fact that the particles were able to influence one another instantaneously at a distance. In fact, the "incorrect" predictions of trajectories by the entangled photon were actually a consequence of where in their course the entangled particles were measured. Considering both particles together, the measurements made sense and were consistent with real trajectories.

Steinberg points out that both the standard interpretation of quantum mechanics and the De Broglie-Bohm interpretation are consistent with experimental evidence, and are mathematically equivalent. But it is helpful in some circumstances to visualize real trajectories, rather than wave function collapses, he says. [8]

Physicists discover easy way to measure entanglement—on a sphere



Entanglement on a sphere: This Bloch sphere shows entanglement for the one-root state ρ and its radial state ρc. The color on the sphere corresponds to the value of the entanglement, which is determined by the distance from the root state z, the point at which there is no entanglement. The closer to z, the less the entanglement (red); the further from z, the greater the entanglement (blue). Credit: Regula and Adesso. ©2016 American Physical Society

Now in a new paper to be published in Physical Review Letters, mathematical physicists Bartosz Regula and Gerardo Adesso at The University of Nottingham have greatly simplified the problem of measuring entanglement.

To do this, the scientists turned the difficult analytical problem into an easy geometrical one. They showed that, in many cases, the amount of entanglement between states corresponds to the distance between two points on a Bloch sphere, which is basically a normal 3D sphere that physicists use to model quantum states.

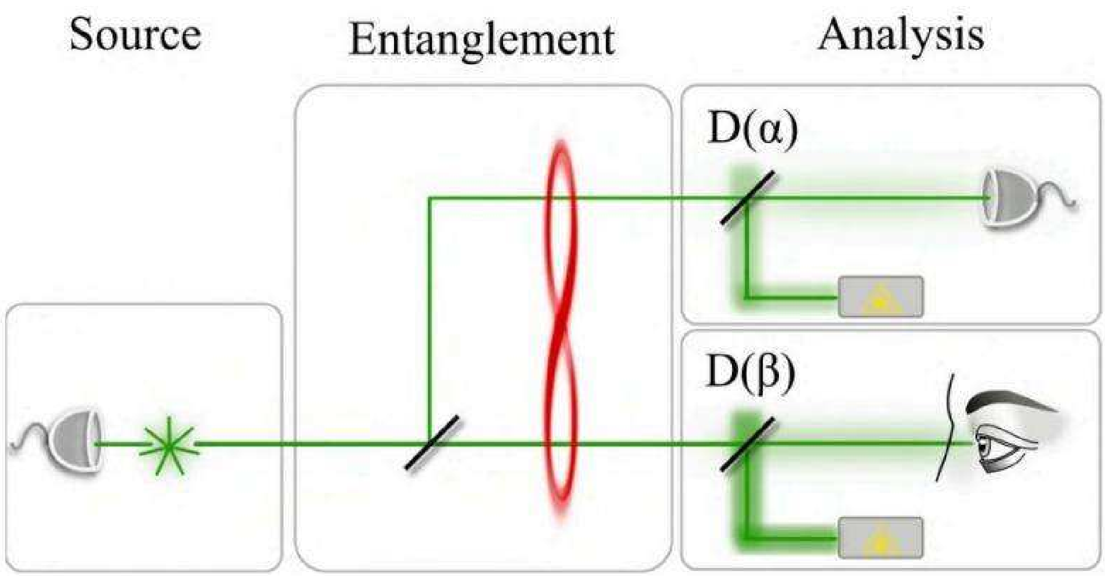
As the scientists explain, the traditionally difficult part of the math problem is that it requires finding the optimal decomposition of mixed states into pure states. The geometrical approach completely eliminates this requirement by reducing the many possible ways that states could decompose down to a single point on the sphere at which there is zero entanglement. The approach requires that there be only one such point, or "root," of zero entanglement, prompting the physicists to describe the method as "one root to rule them all."

The scientists explain that the "one root" property is common among quantum states and can be easily verified, transforming a formidable math problem into one that is trivially easy. They demonstrated that the new approach works for many types of two-, three- and four-qubit entangled states.

"This method reveals an intriguing and previously unexplored connection between the quantum features of a state and classical geometry, allowing all one-root states to enjoy a convenient visual representation which considerably simplifies the study and understanding of their properties," the researchers explained.

The simple way of measuring a state's entanglement could have applications in many technological areas, such as quantum cryptography, computation, and communication. It could also provide insight into understanding the foundations of thermodynamics, condensed matter physics, and biology. [7]

An idea for allowing the human eye to observe an instance of entanglement



Scheme of the proposal for detecting entanglement with the human eye. Credit: arXiv:1602.01907

Entanglement, is of course, where two quantum particles are intrinsically linked to the extent that they actually share the same existence, even though they can be separated and moved apart. The idea was first proposed nearly a century ago, and it has not only been proven, but researchers routinely cause it to occur, but, to date, not one single person has every actually seen it happen—they only know it happens by conducting a series of experiments. It is not clear if anyone has ever actually tried to see it happen, but in this new effort, the research trio claim to have found a way to make it happen—if only someone else will carry out the experiment on a willing volunteer.

The idea involves using a beam splitter and two beans of light—an initial beam of coherent photons fired at the beam splitter and a secondary beam of coherent photons that interferes with the photons in the first beam causing a change of phase, forcing the light to be reflected rather than transmitted. In such a scenario, the secondary beam would not need to be as intense as the first, and could in fact be just a single coherent photon—if it were entangled, it could be used to allow a person to see the more powerful beam while still preserving the entanglement of the original photon.

The researchers suggest the technology to carry out such an experiment exists today, but also acknowledge that it would take a special person to volunteer for such an assignment because to prove that they had seen entanglement taking place would involve shooting a large number of photons in series, into a person's eye, whereby the resolute volunteer would announce whether they had seen the light on the order of thousands of times. [6]

Quantum entanglement

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

The Bridge

The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories. [1]

Accelerating charges

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

Relativistic effect

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

Heisenberg Uncertainty Relation

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

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

Wave – Particle Duality

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

Atomic model

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

The Relativistic Bridge

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

The weak interaction

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

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

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

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

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

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

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

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

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

Finally since the weak interaction is an electric dipole change with ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.
The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.
We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change.
There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.
The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

Fermions and Bosons

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

Van Der Waals force

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

Electromagnetic inertia and mass

Electromagnetic Induction

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

Relativistic change of mass

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

The frequency dependence of mass

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

Electron – Proton mass rate

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

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

Gravity from the point of view of quantum physics

The Gravitational force

The gravitational attractive force is basically a magnetic force.

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

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

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

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

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

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

The Higgs boson

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

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

Higgs mechanism and Quantum Gravity

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

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

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

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

What is the Spin?

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

The Graviton

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

The Secret of Quantum Entanglement

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] When one of the entangled particles wave function is collapses by measurement, the intermediate photon also collapses and transforms its state to the second entangled particle giving it the continuity of this entanglement. Since the accelerated charges are self-maintaining their potential locally causing their acceleration, it seems that they entanglement is a spooky action at a distance.

Conclusions

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

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.

One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .

The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the 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.

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