Multiphoton Entanglement

An entangled polarization state of ten photons sets a new record for multiphoton entanglement. [20]

Experimentalists from three groups have used small clouds of cold atoms to mediate strong interactions between pulses of light containing as little as one photon. [19]

But University of Utah electrical and computer engineering associate professor Rajesh Menon and his team have developed a cloaking device for microscopic photonic integrated devices—the building blocks of photonic computer chips that run on light instead of electrical current—in an effort to make future chips smaller, faster and consume much less power. [18]

In 1959 renowned physicist Richard Feynman, in his talk "Plenty of Room at the Bottom," spoke of a future in which tiny machines could perform huge feats. Like many forward-looking concepts, his molecule and atom-sized world remained for years in the realm of science fiction. [17]

The race towards quantum computing is heating up. Faster, brighter, more exacting – these are all terms that could be applied as much to the actual science as to the research effort going on in labs around the globe. [16]

For the first time, scientists now have succeeded in placing a complete quantum optical structure on a chip, as outlined Nature Photonics. This fulfills one condition for the use of photonic circuits in optical quantum computers. [15]

The intricately sculpted device made by Paul Barclay and his team of physicists is so tiny it can only be seen under a microscope. But their diamond microdisk could lead to huge advances in computing, telecommunications, and other fields. [14]

Researchers from the Institute for Quantum Computing at the University of Waterloo and the National Research Council of Canada (NRC) have, for the first time, converted the color and bandwidth of ultrafast single photons using a room-temperature quantum memory in diamond. [13]

One promising approach for scalable quantum computing is to use an all-optical architecture, in which the qubits are represented by photons and manipulated by mirrors and beam splitters. So far, researchers have demonstrated this method, called Linear Optical Quantum Computing, on a very small scale by performing operations using just a few photons. In an attempt to scale up this method to larger numbers of photons, researchers in a *new study have developed a way to fully integrate single-photon sources inside optical circuits, creating integrated quantum circuits that may allow for scalable optical quantum computation. [12]*

Spin-momentum locking might be applied to spin photonics, which could hypothetically harness the spin of photons in devices and circuits. Whereas microchips use electrons to perform computations and process information, photons are limited primarily to communications, transmitting data over optical fiber. However, using the spin of light waves could make possible devices that integrate electrons and photons to perform logic and memory operations. [11]

Researchers at the University of Ottawa observed that twisted light in a vacuum travels slower than the universal physical constant established as the speed of light by Einstein's theory of relativity. Twisted light, which turns around its axis of travel much like a corkscrew, holds great potential for storing information for quantum computing and communications applications. [10]

We demonstrated the feasibility and the potential of a new approach to making a quantum computer. In our approach, we replace the qubits with qumodes. Our method is advantageous because the number of qumodes can be extremely large. This is the case, for instance, in hundred–thousand mode, octave-spanning optical frequency combs of carrier-envelope phase-locked classical femtosecond lasers. [9]

IBM scientists today unveiled two critical advances towards the realization of a practical quantum computer. For the first time, they showed the ability to detect and measure both kinds of quantum errors simultaneously, as well as demonstrated a new, square quantum bit circuit design that is the only physical architecture that could successfully scale to larger dimensions. [8]

Physicists at the Universities of Bonn and Cambridge have succeeded in linking two completely different quantum systems to one another. In doing so, they have taken an important step forward on the way to a quantum computer. To accomplish their feat the researchers used a method that seems to function as well in the quantum world as it does for us people: teamwork. The results have now been published in the "Physical Review Letters". [7]

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.

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.

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Author: George Rajna

Preface

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

Using a square lattice, IBM is able to detect both types of quantum errors for the first time. This is the best configuration to add more qubits to scale to larger systems. [8]

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.

Synopsis: Ten Photons in a Tangle

Quantum computing requires multiple qubits entangled together. So far, only a handful of qubits have been coupled together successfully. A new experiment raises the bar with the entangling of ten photons, two more than the previous photon record. While still a ways off from what’s needed to make quantum computers competitive with classical ones, the entanglement of this many photons might be sufficient for certain quantum error correction codes and teleportation experiments.

Entangling photons typically relies on a nonlinear crystal, which converts a small fraction of incoming photons into a pair of entangled photons. In the case of the ß??-barium borate (BBO) crystal, the two photons have opposite polarizations—one being horizontal, the other vertical—and they are emitted in different directions. Researchers therefore use a variety of optical devices to collect the photon pair, which can then be entangled with pairs from other BBO crystals.

Previous multiphoton entanglement experiments had relatively low collection efficiencies of around 40%. Xi-Lin Wang from the University of Science and Technology of China and colleagues have developed a system with 70% collection efficiency. Rather than using a single BBO crystal to create pairs, they utilize two closely spaced BBO crystals separated by a polarization-rotating plate. This “sandwich” configuration generates entangled pairs of photons traveling in the same direction with the same polarization. The boost in efficiency from this output alignment means Wang and colleagues can achieve a high count rate with relatively low input power. To create ten-photon entanglement, the team placed five sandwich structures in a row and illuminated them all with a 0.57-W laser. They then used polarizing beam splitters to combine the photon pairs from each BBO crystal together.

This research is published in Physical Review Letters. [20]

Viewpoint: Optical Quantum Logic at the Ultimate Limit

Photons—individual quanta of light—are painfully shy when it comes to interacting with each other in free space; for a start, their extreme speed doesn't help matters. This shyness, and speed, is good from the point of view of faithfully and rapidly transmitting quantum information, but it poses a major challenge to the realization of optical quantum logic gates that use single photons as inputs and outputs. However, what if the photons could be slowed down or even stopped for a while in a special medium through which they could be forced to “talk” to each other? This is the approach taken in three exciting recent experiments [1–3], which used an ensemble of trapped, laser-cooled atoms as the special medium. The researchers showed that in this medium, a pulse of light containing, on average, as little as one photon can interact with, and produce a phase shift of up to 180° on, another, similarly weak pulse (Fig. 1). This result fulfils the requirements of a deterministic (that is, nonprobabilistic) and universal quantum logic gate.

The polarization of a single photon (horizontal, vertical, or any quantum superposition of the two) serves nicely as a quantum bit, or qubit. A two-qubit quantum logic gate requires that the output state of the qubits depends in a conditional, nonlinear way on each of their input states—for example, that the photons interact only for one particular combination of polarizations. But for the most part, photons in free space just plain ignore each other. The potential to use atomic media to create the necessary interactions between photons has been known for some time. It was highlighted by a seminal experiment performed by the group of Jeff Kimble at Caltech in 1995 [4]. In that experiment, two continuous-wave weak laser beams, differing slightly in frequency, were passed simultaneously through a small optical resonator containing, on average, just a single cesium atom from an atomic beam. Through the strong coupling of the atom to the laser light confined inside the resonator, it was possible for one beam to impart a nonlinear, polarization-dependent phase shift on the other of up to 16° per photon.

However, the step from continuous, albeit weak, laser beams to few- or single-photon light pulses, as was demonstrated in the new experiments [1–3], is a nontrivial one. Whereas the light in a continuous laser beam has essentially a single frequency, a pulse of light has a spread of frequency components, that is, a finite bandwidth. In particular, the longer the pulse, the smaller the bandwidth, and vice versa. The medium through which simultaneously propagating photons interact must also, in practice, have a finite working bandwidth; in the case of the Caltech experiment, this was the inverse of the lifetime of a photon inside the resonator, or the resonator linewidth. For all frequency components of the pulse to experience the same phase shift, the pulse bandwidth must fit within this linewidth. Equivalently, the pulse duration must be much longer than the duration of the interaction. But then, on average, only a small “fraction” of each photon pulse can ever be participating in the interaction, effectively reducing the interaction strength. In fact, it was shown [5, 6] that this trade-off between interaction time and strength, or between bandwidths, leads to a fundamental limit on the achievable phase shift in experiments such as that of Kimble and colleagues [4].

But here enters the fascinating world of “slow light” and the phenomenon of electromagnetically induced transparency (EIT) [7, 8]. EIT occurs when the absorption of “probe” light by an atomic medium is eliminated because of destructive interference between two alternative pathways for a transition from a ground state to an excited atomic state. The different pathways are achieved by involving a third atomic state, which is coupled to the excited state via an auxiliary laser field. The strength of this field determines the bandwidth of the transparency. Significantly, a change in absorption over a sufficiently narrow bandwidth is accompanied by a sharp change in the medium's refractive index and thus a dramatic slowing of the probe light. And this is precisely the effect that the authors of the recent studies [1–3] have employed to force the interaction between weak light pulses propagating through a cold-atom medium, and thereby circumvent the fundamental limit on phase shifts.

Stephan Dürr and colleagues [1] at the Max Planck Institute for Quantum Optics, Germany, slowed an initial "control" pulse—containing, on average, less than one photon—to a standstill for a few microseconds in a microscopic cloud of approximately ten thousand rubidium atoms. The researchers attained this by switching off the auxiliary laser during the passage of the control pulse through the cloud. This effectively reduced the group velocity of the pulse to zero, allowing a single control photon to be stored as an excitation of the third atomic state—in this instance, a high-lying Rydberg state of one atom in the cloud. In keeping with a theoretical proposal [9], the presence of this Rydberg atom and, in particular, its strong influence on other atoms within the cloud, produced a substantial phase shift—up to 180°—on a "target" pulse that subsequently propagated through the cloud. Finally, the authors switched back on the control photon's auxiliary laser, retrieving the photon and completing an "AND gate" operation. This is the essence of a two-qubit controlled-phase gate, and any operation on a quantum computer—universal quantum computation—can be reduced to sequences of this gate and simple one-qubit (or single-photon) gates.

Similarly, Vladan Vuletic and co-workers [2] at the Massachusetts Institute of Technology, Cambridge, stored a photon from a weak pulse through EIT in an ensemble of cold cesium atoms. However, the authors used a hyperfine ground state as the third atomic state and stored the photon as a collective (or spin) excitation of the ensemble. In addition, as in Kimble and colleagues' experiment [4], they placed the ensemble inside an optical resonator, through which a subsequent, propagating pulse could couple strongly to the third atomic state and impart a differential phase shift of up to 60° between the two atomic states involved in the collective excitation. Then, by reapplying the auxiliary laser, they retrieved the stored and phase-shifted photon pulse to complete the gate operation.

Finally, Ite Yu from the National Tsing Hua University, Taiwan, and colleagues [3] made two pulses—each containing, on average, eight photons—propagate slowly and simultaneously through a cold-atom cloud in which two EIT configurations overlapped. This double-EIT system involved four atomic levels (two excited and two ground atomic states) and two auxiliary lasers, similar in spirit to an original proposal [10]. By sharing atomic ground states, the overlapping EIT configurations enabled strong interaction between the pulses and a phase shift to be induced on one pulse by the other. The shift is equivalent to 26° per photon, with the prospect of further improvement.

As impressive as these schemes are, challenges remain in optimizing their performance. For example, the storage and subsequent recovery of photons is currently far from perfect, with efficiency of around 10–20%, due to several imperfections, such as uncontrolled photon scattering and nonuniform atom-light coupling across the clouds. The schemes should also be implemented using actual single-photon pulses, rather than weak pulses that have one or a few photons on average, and the photon polarization should be brought into play explicitly to implement a qubit with each photon. Nonetheless, together these experiments provide a compelling demonstration of the potential of slow light in atomic media and, in particular, the exquisite degree of control that experimentalists can now exert over the interactions of single photons with one another.

This research is published in Science Advances, Proceedings of the National Academy of Sciences, and Physical Review Letters. [19]

Engineers develop invisibility cloak for high-tech processing chips

From Harry Potter's Cloak of Invisibility to the Romulan cloaking device that rendered their warship invisible in "Star Trek," the magic of invisibility was only the product of science fiction writers and dreamers.

But University of Utah electrical and computer engineering associate professor Rajesh Menon and his team have developed a cloaking device for microscopic photonic integrated devices—the building blocks of photonic computer chips that run on light instead of electrical current—in an effort to make future chips smaller, faster and consume much less power.

Menon's discovery was published online Wednesday in the latest edition of the science journal, Nature Communications. The paper was co-written by University of Utah doctoral student Bing Shen and Randy Polson, senior optical engineer in the U's Utah Nanofab.

The future of computers, data centers and mobile devices will involve photonic chips in which data is shuttled around and processed as light photons instead of electrons. The advantages of photonic chips over today's silicon-based chips are they will be much faster and consume less power and therefore give off less heat. And inside each chip are potentially billions of photonic devices, each with a specific function in much the same way that billions of transistors have different functions inside today's silicon chips. For example, one group of devices would perform calculations, another would perform certain processing, and so on.

The problem, however, is if two of these photonic devices are too close to each other, they will not work because the light leakage between them will cause "crosstalk" much like radio interference. If they are spaced far apart to solve this problem, you end up with a chip that is much too large.

So Menon and his team discovered you can put a special nanopatterened silicon-based barrier in between two of the photonic devices, which acts like a "cloak" and tricks one device from not seeing the other.

"The principle we are using is similar to that of the Harry Potter invisibility cloak," Menon says. "Any light that comes to one device is redirected back as if to mimic the situation of not having a neighboring device. It's like a barrier—it pushes the light back into the original device. It is being fooled into thinking there is nothing on the other side."

Consequently, billions of these photonic devices can be packed into a single chip, and a chip can contain more of these devices for even more functionality. And since these photonic chips use light photons instead of electrons to transfer data, which builds up heat, these chips potentially could consume 10 to 100 times less power, which would be a boon for places like data centers that use tremendous amounts of electricity.

Menon believes the most immediate application for this technology and for photonic chips in general will be for data centers similar to the ones used by services like Google and Facebook. According to a study from the U.S. Department of Energy's Lawrence Berkeley National Laboratory, data centers just in the U.S. consumed 70 billion kilowatt hours in 2014, or about 1.8 percent of total U.S. electricity consumption. And that power usage is expected to rise another 4 percent by 2020.

"By going from electronics to photonics we can make computers much more efficient and ultimately make a big impact on carbon emissions and energy usage for all kinds of things," Menon says. "It's a big impact and a lot of people are trying to solve it."

Currently, photonic devices are used mostly in high-end military equipment, and he expects full photonic-based chips will be employed in data centers within a few years. [18]

A tiny machine: Engineers design an infinitesimal computing device

In 1959 renowned physicist Richard Feynman, in his talk "Plenty of Room at the Bottom," spoke of a future in which tiny machines could perform huge feats. Like many forward-looking concepts, his molecule and atom-sized world remained for years in the realm of science fiction.

And then, scientists and other creative thinkers began to realize Feynman's nanotechnological visions.

In the spirit of Feynman's insight, and in response to the challenges he issued as a way to inspire scientific and engineering creativity, electrical and computer engineers at UC Santa Barbara have developed a design for a functional nanoscale computing device. The concept involves a dense, three-dimensional circuit operating on an unconventional type of logic that could, theoretically, be packed into a block no bigger than 50 nanometers on any side.

"Novel computing paradigms are needed to keep up with the demand for faster, smaller and more energy-efficient devices," said Gina Adam, postdoctoral researcher at UCSB's Department of Computer Science and lead author of the paper "Optimized stateful material implication logic for three dimensional data manipulation," published in the journal Nano Research. "In a regular computer, data processing and memory storage are separated, which slows down computation. Processing data directly inside a three-dimensional memory structure would allow more data to be stored and processed much faster."

While efforts to shrink computing devices have been ongoing for decades—in fact, Feynman's challenges as he presented them in his 1959 talk have been met—scientists and engineers continue to carve out room at the bottom for even more advanced nanotechnology. A nanoscale 8-bit adder operating in 50-by-50-by-50 nanometer dimension, put forth as part of the current Feynman Grand Prize challenge by the Foresight Institute, has not yet been achieved. However, the continuing development and fabrication of progressively smaller components is bringing this virus-sized computing device closer to reality, said Dmitri Strukov, a UCSB professor of computer science.

"Our contribution is that we improved the specific features of that logic and designed it so it could be built in three dimensions," he said.

Key to this development is the use of a logic system called material implication logic combined with memristors—circuit elements whose resistance depends on the most recent charges and the directions of those currents that have flowed through them. Unlike the conventional computing logic and circuitry found in our present computers and other devices, in this form of computing, logic operation and information storage happen simultaneously and locally. This greatly reduces the need for components and space typically used to perform logic operations and to move data back and forth between operation and memory storage. The result of the computation is immediately stored in a memory element, which prevents data loss in the event of power outages—a critical function in autonomous systems such as robotics.

In addition, the researchers reconfigured the traditionally two-dimensional architecture of the memristor into a three-dimensional block, which could then be stacked and packed into the space required to meet the Feynman Grand Prize Challenge.

"Previous groups show that individual blocks can be scaled to very small dimensions, let's say 10-by-10 nanometers," said Strukov, who worked at technology company Hewlett-Packard's labs when they ramped up development of memristors and material implication logic. By applying those results to his group's developments, he said, the challenge could easily be met.

The tiny memristors are being heavily researched in academia and in industry for their promising uses in memory storage and neuromorphic computing. While implementations of material implication logic are rather exotic and not yet mainstream, uses for it could pop up any time, particularly in energy scarce systems such as robotics and medical implants.

"Since this technology is still new, more research is needed to increase its reliability and lifetime and to demonstrate large scale three-dimensional circuits tightly packed in tens or hundreds of layers," Adam said. [17]

Quantum research race lights up the world

The race towards quantum computing is heating up. Faster, brighter, more exacting – these are all terms that could be applied as much to the actual science as to the research effort going on in labs around the globe.

Quantum technologies are poised to provide exponentially stronger computational power and secured communications. But the bar is high – advances are hard won and competition is intense.

At the forefront of the candidates to implement such technologies is the field of quantum photonics, particularly light sources that emit photons one at a time to be used as carriers of information.

Quantum technologies require the quantum analogue to the classical "information bit" that is used to encode zeros and ones, and a means to transfer the information. Photons can do both. Single photon sources, such as point defects in solids, can be used as quantum bits. Photons generated by the defects can then carry the information from node to node, in a similar way to conventional integrated circuits. The challenge is: how to find and engineer those sources.

Associate Professors Igor Aharonovich and Milos Toth, from the Faculty of Science at UTS, are working on engineering new ultra-bright and super-efficient sources from emerging 2D platforms.

Aharonovich and Toth, writing the cover story for the latest issue of Nature Photonics with their long-time collaborator Professor Dirk Englund of MIT, have laid out a road map showing what needs to be done to realise quantum emitters that are good enough for real-world technologies.

The scientists have drawn on their own extensive research as well as the achievements of hundreds of other scientists around the world to summarise the state of play with solid-state single-photon sources.

"Photonic technologies are becoming increasingly prevalent in our daily lives. After decades of rapid advances, light sources – especially lasers and light-emitting diodes (LEDs) – have become high-performance, yet low-cost and reliable components, driving the internet and lighting cities," they write.

The next frontier of research is the development of non-classical light sources: sources that produce streams of photons with controllable quantum relationships.

"The required toolkit is in place, primarily because a vast library of single-photon emitters has already been established. It is therefore the right time to dedicate resources to scalability, optimisation and applicability of these emitters to real devices."

In a nutshell, the noteworthy developments are:

Solid-state systems are promising. Students enjoy working with them, holding "quantum systems" in their hands.

Requirements for the sources are high – they must be bright and easy to engineer and scale up. In recent years we have seen a 10-fold improvement in brightness and availability of sources. The achievements are comparable to the six-decade transformation of television – from cathode ray tube to state-of-the-art flat screens made from LEDs

Many groups are pursuing this via a range of approaches – studying different platforms, methods of engineering and characterization.

New platforms are emerging, including quantum dots, diamond, carbon nanotubes and 2D materials. [16]

First quantum photonic circuit with an electrically driven light source

Whether for use in safe data encryption, ultrafast calculation of huge data volumes or so-called quantum simulation of highly complex systems: Optical quantum computers are a source of hope for tomorrow's computer technology. For the first time, scientists now have succeeded in placing a complete quantum optical structure on a chip, as outlined Nature Photonics. This fulfills one condition for the use of photonic circuits in optical quantum computers.

"Experiments investigating the applicability of optical quantum technology so far have often claimed whole laboratory spaces," explains Professor Ralph Krupke of the KIT. "However, if this technology is to be employed meaningfully, it must be accommodated on a minimum of space." Participants in the study were scientists from Germany, Poland, and Russia under the leadership of Professors Wolfram

Pernice of the Westphalian Wilhelm University of Münster (WWU) and Ralph Krupke, Manfred Kappes, and Carsten Rockstuhl of the Karlsruhe Institute of Technology (KIT).

The light source for the quantum photonic circuit used by the scientists for the first time were special nanotubes made of carbon. They have a diameter 100,000 times smaller than a human hair, and they emit single light particles when excited by laser light. Light particles (photons) are also referred to as light quanta. Hence the term "quantum photonics."

That carbon tubes emit single photons makes them attractive as ultracompact light sources for optical quantum computers. "However, it is not easily possible to accommodate the laser technology on a scalable chip," admits physicist Wolfram Pernice. The scalability of a system, i.e. the possibility to miniaturize components so as to be able to increase their number, is a precondition for this technology to be used in powerful computers up to an optical quantum computer.

As all elements on the chip now developed are triggered electrically, no additional laser systems are required any more, which is a marked simplification over the optical excitation normally used. "The development of a scalable chip on which a single-photon source, detector, and waveguide are combined, is an important step for research," emphasizes Ralph Krupke, who conducts research at the KIT Institute for Nanotechnology and the Institute of Materials Science of the Darmstadt Technical University. "As we were able to show that single photons can be emitted also by electric excitation of the carbon nanotubes, we have overcome a limiting factor so far preventing potential applicability."

About the methodology: The scientists studied whether the flow of electricity through carbon nanotubes caused single light quanta to be emitted. For this purpose, they used carbon nanotubes as single-photon sources, superconducting nanowires as detectors, and nanophotonic waveguides. One single-photon source and two detectors each were connected with one waveguide. The structure was cooled with liquid helium to allow single light quanta to be counted. The chips were produced in an electron beam scribing device.

The scientists' work is fundamental research. It is not yet clear whether and when it will lead to practical applications. Wolfram Pernice and the first author, Svetlana Khasminskaya, were supported by the Deutsche Forschungsgemeinschaft and the Helmholtz-Gemeinschaft, Ralph Krupke was funded by the Volkswagen Foundation. [15]

Physicists create nano-sized device with huge potential in field of quantum computing

The intricately sculpted device made by Paul Barclay and his team of physicists is so tiny it can only be seen under a microscope. But their diamond microdisk could lead to huge advances in computing, telecommunications, and other fields.

Barclay and his research group—part of the University of Calgary's Institute for Quantum Science and Technology and the National Institute of Nanotechnology—have made the first-ever nano-sized optical resonator (or optical cavity) from a single crystal of diamond that is also a mechanical resonator.

The team also measured—in the coupling of light and mechanical motion in the device—the high-frequency, long-lasting mechanical vibrations caused by the energy of light trapped and bouncing inside the diamond microdisk optical cavity.

"Diamond optomechanical devices offer a platform to study the quantum behaviour of microscopic objects," says Barclay, associate professor of physics and astronomy and Alberta Innovates Scholar in Quantum Nanotechnology in the Faculty of Science.

"These devices also have many potential applications, including state-of-the-art sensing, technology for shifting the colour of light, and quantum information and computing technologies."

The team's work is published in the peer-reviewed journal Optic, "Single-Crystal Diamond Low-Dissipation Cavity Optomechanics."

Advancing technology and quantum research

Quantum nanophotonics involves developing micro and nanoscale (about 100 times smaller than the width of a human hair) circuits for manipulating light.

Instead of microcircuits in which electricity is conducted by wires—found in computers, cell phones and other telecommunication technologies—nanophotonics involves transmitting light through wires. It's like fibre optic technology, but at a much smaller and potentially more complex scale, allowing information to be transmitted more densely and more efficiently.

Nanophotonic technology also is a boon to researchers exploring new regimes of quantum physics—the nature of matter and energy on the atomic and subatomic level.

"The ability to trap light in nanoscale volumes in an optical cavity creates high electromagnetic intensity from tiny amounts of light, and amplifies light-matter interactions that are typically nearly impossible to study," Barclay says.

Diamond: a quantum researcher's 'best friend'

Barclay's group used diamond to make their microdisk, which looks like a microscopic-sized hockey puck (the optical cavity) supported by a very tiny hourglass-shaped pillar in the centre.

The group used light to vibrate the disk to a gigahertz frequency, the frequency used in computers and cell phone transmission. "It shows that diamond has a lot of potential as a material for making mechanical oscillators at this scale," Barclay says.

"Imagine taking a tuning fork made of diamond and ringing it. It's going to ring at a very high frequency for a really long time. This also helps us measure these delicate quantum effects."

Students fabricated the device

Barclay's PhD students, including Matthew Mitchell and Behzad Khanaliloo, lead authors on the paper, fabricated the microdisk from commercially available synthetic, single-crystal diamond chips. The students also designed and built the system to measure the device's optical and mechanical properties.

The group, which included doctoral student David Lake, master's student Tamiko Masuda and postdoctoral scholar J.P. Hadden, used facilities at the National Institute for Nanotechnology (NINT) and the University of Alberta's nanoFAB.

"By essentially inventing a new nano-fabrication process for single-crystal diamond, we have demonstrated a device that is pushing the state of the art in cavity optomechanics," Mitchell says. "It holds great promise for realizing an on-chip platform to control the interaction of light, vibrations and electrons."

Khanalioo says: "We're excited about using these devices for devising ways to create connections for quantum computers."

"Just making the device, within the nanophotonics research community, is an accomplishment," Barclay notes. "I would say we're one of the best groups in the world, thanks to the work of the students, in creating optical probes to get light into and out of these devices." [14]

Changing the color of single photons in a diamond quantum memory

Researchers from the Institute for Quantum Computing at the University of Waterloo and the National Research Council of Canada (NRC) have, for the first time, converted the colour and bandwidth of ultrafast single photons using a room-temperature quantum memory in diamond.

Shifting the colour of a photon, or changing its frequency, is necessary to optimally link components in a quantum network. For example, in optical quantum communication, the best transmission through an optical fibre is near infrared, but many of the sensors that measure them work much better for visible light, which is a higher frequency. Being able to shift the colour of the photon between the fibre and the sensor enables higher performance operation, including bigger data rates.

The research, published in Nature Communications, demonstrated small frequency shifts that are useful for a communication protocol known as wavelength division multiplexing. This is used today when a sender needs to transmit large amounts of information through a transmission so the signal is broken into smaller packets of slightly different frequencies and sent through together. The information is then organized at the other end based on those frequencies.

In the experiments conducted at NRC, the researchers demonstrated the conversion of both the frequency and bandwidth of single photons using a room-temperature diamond quantum memory.

"Originally there was this thought that you just stop the photon, store it for a little while and get it back out. The fact that we can manipulate it at the same time is exciting," said Kent Fisher a PhD student at the Institute for Quantum Computing and with the Department of Physics and Astronomy at Waterloo. "These findings could open the door for other uses of quantum memory as well."

The diamond quantum memory works by converting the photon into a particular vibration of the carbon atoms in the diamond, called a phonon. This conversion works for many different colours of light allowing for the manipulation of a broad spectrum of light. The energy structure of diamond allows for this to occur at room temperature with very low noise. Researchers used strong laser pulses to store and retrieve the photon. By controlling the colours of these laser pulses, researchers controlled the colour of the retrieved photon.

"The fragility of quantum systems means that you are always working against the clock," remarked Duncan England, researcher at NRC. "The interesting step that we've shown here is that by using extremely short pulses of light, we are able to beat the clock and maintain quantum performance."

The integrated platform for photon storage and spectral conversion could be used for frequency multiplexing in quantum communication, as well as build up a very large entangled state – something called a cluster state. Researchers are interested in exploiting cluster states as the resource for quantum computing driven entirely by measurements.

"Canada is a powerhouse in quantum research and technology. This work is another example of what partners across the country can achieve when leveraging their joint expertise to build next-generation technologies," noted Ben Sussman, program leader for NRC's Quantum Photonics program. [13]

Quantum computing with single photons getting closer to reality

One promising approach for scalable quantum computing is to use an all-optical architecture, in which the qubits are represented by photons and manipulated by mirrors and beam splitters. So far, researchers have demonstrated this method, called Linear Optical Quantum Computing, on a very small scale by performing operations using just a few photons. In an attempt to scale up this method to larger numbers of photons, researchers in a new study have developed a way to fully integrate single-photon sources inside optical circuits, creating integrated quantum circuits that may allow for scalable optical quantum computation.

The researchers, Iman Esmaeil Zadeh, Ali W. Elshaari, and coauthors, have published a paper on the integrated quantum circuits in a recent issue of Nano Letters.

As the researchers explain, one of the biggest challenges facing the realization of an efficient Linear Optical Quantum Computing system is integrating several components that are usually incompatible with each other onto a single platform. These components include a single-photon source such as quantum dots; routing devices such as waveguides; devices for manipulating photons such as cavities, filters, and quantum gates; and single-photon detectors.

In the new study, the researchers have experimentally demonstrated a method for embedding single-photon-generating quantum dots inside nanowires that, in turn, are encapsulated in a waveguide. To do this with the high precision required, they used a "nanomanipulator" consisting of a tungsten tip to transfer and align the components. Once inside the waveguide, single photons could be selected and routed to different parts of the optical circuit, where logical operations can eventually be performed.

"We proposed and demonstrated a hybrid solution for integrated quantum optics that exploits the advantages of high-quality single-photon sources with well-developed silicon-based photonics," Zadeh, at Delft University of Technology in The Netherlands, told Phys.org. "Additionally, this method, unlike previous works, is fully deterministic, i.e., only quantum sources with the selected properties are integrated in photonic circuits.

"The proposed approach can serve as an infrastructure for implementing scalable integrated quantum optical circuits, which has potential for many quantum technologies. Furthermore, this platform provides new tools to physicists for studying strong light-matter interaction at nanoscales and cavity QED [quantum electrodynamics]."

One of the most important performance metrics for Linear Optical Quantum Computing is the coupling efficiency between the single-photon source and photonic channel. A low efficiency indicates photon loss, which reduces the computer's reliability. The set-up here achieves a coupling efficiency of about 24% (which is already considered good), and the researchers estimate that optimizing the waveguide design and material could improve this to 92%.

In addition to improving the coupling efficiency, in the future the researchers also plan to demonstrate on-chip entanglement, as well as increase the complexity of the photonic circuits and single-photon detectors.

"Ultimately, the goal is to realize a fully integrated quantum network on-chip," said Elshaari, at Delft University of Technology and the Royal Institute of Technology (KTH) in Stockholm. "At this moment there are a lot of opportunities, and the field is not well explored, but on-chip tuning of sources and generation of indistinguishable photons are among the challenges to be overcome." [12]

Spinning light waves might be 'locked' for photonics technologies

Scientists already knew that light waves have an electric field that can rotate as they propagate, which is known as the polarization property of light, and that light waves carry momentum in their direction of motion. In new findings, researchers have discovered a "spin-momentum locking," meaning, for example, light waves that spin in a counterclockwise direction can only move forward, and vice versa.

"Researchers had noticed intriguing effects related to directional propagation of light coupled to its polarization," said Zubin Jacob, an assistant professor of electrical and computer engineering at Purdue University. "What we have shown is that this is a unique effect related to the spin and momentum of light analogous in many ways to the case of spin-momentum locking which occurs for electrons. We showed there is a very simple rule that governs this spin and momentum locking.

And it's a universal property for all optical materials and nanostructures, which makes it potentially very useful for photonic devices. This universality is unique to light and does not occur for electrons."

Findings were detailed in a research paper that appeared in February in the journal Optica, published by the The Optical Society. The paper was authored by graduate student Todd Van Mechelen and Jacob, who demonstrated spin-momentum locking through analytical theory.

Spin-momentum locking might be applied to spin photonics, which could hypothetically harness the spin of photons in devices and circuits. Whereas microchips use electrons to perform computations and process information, photons are limited primarily to communications, transmitting data over optical fiber. However, using the spin of light waves could make possible devices that integrate electrons and photons to perform logic and memory operations.

"Lots of researchers in the field of electronics think future devices will utilize not only the charge of the electron but also the spin of the electron, a field called spintronics," Jacob said. "The question is how to interface photonics and spintronics. We would have to use some of these spin properties of light to interface with spintronics so that we might use both photons and electrons in devices."

The researchers learned that spin-momentum locking is inevitable when light waves decay.

"If you transmit light along an optical fiber, most of the light is confined within the fiber but a small portion falls outside of the fiber, and this we refer to as the decaying evanescent light wave," Jacob said. "What we showed was that these evanescent waves are the fundamental reason spin-momentum locking is ubiquitous in practical scenarios."

The work is ongoing and may include experiments using a levitating nanoparticle to study the spin-momentum properties of light. [11]

Observation of twisted optical beam traveling slower than the speed of light

Researchers at the University of Ottawa observed that twisted light in a vacuum travels slower than the universal physical constant established as the speed of light by Einstein's theory of relativity. Twisted light, which turns around its axis of travel much like a corkscrew, holds great potential for storing information for quantum computing and communications applications.

In The Optical Society's journal for high impact research, Optica, the researchers report that twisted light pulses in a vacuum travel up to 0.1 percent slower than the speed of light, which is 299,792,458 meters per second. Although light does slow down when traveling through clear dense materials such glass or water, this is the first time that scientists have shown that twisting light can slow it down.

"Anyone who wants to use twisted light for quantum communication should be aware of this effect," said Ebrahim Karimi, assistant professor at the University of Ottawa and leader of the research team. "If they don't compensate for the slow-light effect, information coded on twisted light might not arrive in the right order. Propagation speeds can significantly affect many protocols related to quantum communication."

Benefits of twisted light

Most people are familiar with the solid spot found in laser pointers created by Gaussian laser beams. In contrast, the corkscrew shape of twisted light creates a donut shape when shone on a surface. The light can carry an infinite number of twists over one wavelength.

Karimi and Frederic Bouchard, a graduate student in Karimi's lab and the paper's first author, are studying twisted light because of its great potential for quantum communication and quantum computers. Today, light is used to encode information by either varying the number of photons emitted or switching between light's two polarization states. Twisted light offers the advantage that each twist can encode a different value or letter, allowing the encoding of a great deal more information using less light. Twisted light might one day offer a quantum-based communication method that uses less energy and is more secure than today's methods.

The researchers first noticed the slow speed of twisted light when conducting experiments with Gaussian laser light and light with 10 twists. "We realized that the two beams didn't arrive at the detector at the same time," Karimi said. "The twisted light was slower, which was surprising until we realized that the twists make the beam tilt slightly as it propagates. This tilt means that the twisted light beam doesn't take the straightest, and thus fastest, path between two points."

Measuring the delay

Once the scientists understood that the time delay came from the twisted nature of the light, they set about the challenging task of measuring the delay, which they calculated to be on the order of tenths of a femtosecond (one quadrillionth of a second). After a year of searching for a capable measurement method, they connected with nonlinear optics scientists who suggested they modify an approach known as frequency-resolved optical gating (FROG) that is used to measure ultrashort laser pulses.

Using the modified FROG approach, Karimi's research team worked with Robert Boyd's team, also at the University of Ottawa, to compare Gaussian beams with different types of twisted light. They found that increasing the number of twists further slowed the light. They measured delays as long as 23 femtoseconds for the twisted light beams.

"The type of precision that can be measured using FROG was not previously used in the quantum optics community, and thus scientists in this area were not aware that twisted light traveled slower than the speed of light," Karimi said.

If it's possible to slow the speed of light by altering its structure, it may also be possible to speed up light. The researchers are now planning to use FROG to measure other types of structured light that their calculations have predicted may travel around 1 femtosecond faster than the speed of light in a vacuum. [10]

Time- and frequency-resolved quantum optics for large-scale quantum computing

In our approach, we use an optical parametric oscillator (OPO) rather than a laser. The cavity of an OPO contains a second-order nonlinear medium (instead of a one-photon-emitting laser gain medium) in which photons are created in pairs from the annihilation of pump photons. This photon pair emission, into two distinct OPO qumodes, produces entanglement between the qumode optical fields. In our group, we used carefully designed periodically poled potassium titanyl phosphate crystals as well as exquisitely controlled interference between the OPO qumodes of the same frequency and orthogonal polarizations to create prototype quantum processors in the laboratory. These processors have a confirmed—record—size of 60 qumodes entangled over frequency and polarization,9, 10 with an expected size of 3000 entangled qumodes.14 In parallel, work at the University of Tokyo (led by Akira Furusawa)—also in collaboration with the Menicucci group—has demonstrated 104 sequentially entangled qumodes, although these are accessible only two at a time.11

We propose15,16 that a scalable square-lattice cluster state can be generated over qumodes by combining existing quantum optical technologies (i.e., that yielded unidimensional cluster states in the frequency and time domains). Our experimental setup is illustrated in Figure 1. It is based on a principle in which the initial entangled qumode pairs emitted by the OPO are first ‘threaded’ into 1D frequency ‘wires’ (as has previously been demonstrated).10 We then separate these wires (in a somewhat artificial, but nonetheless rigorous, approach by fulfilling the musical score condition) into different temporal bins. These bins are then, in turn, ‘weaved’ into the time-frequency square lattice (depicted in lower left of Figure 1).

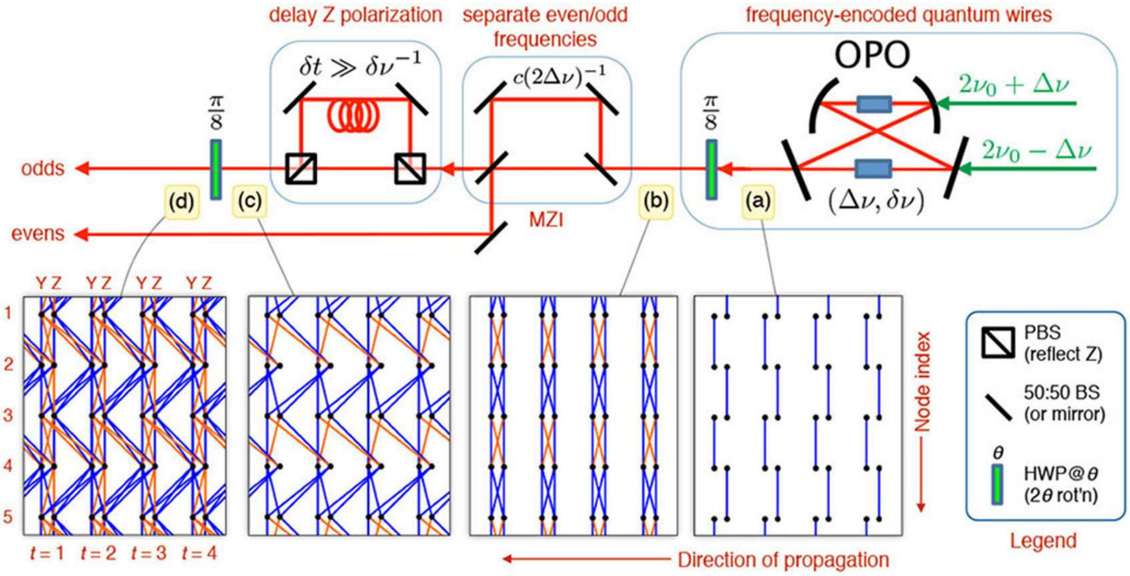
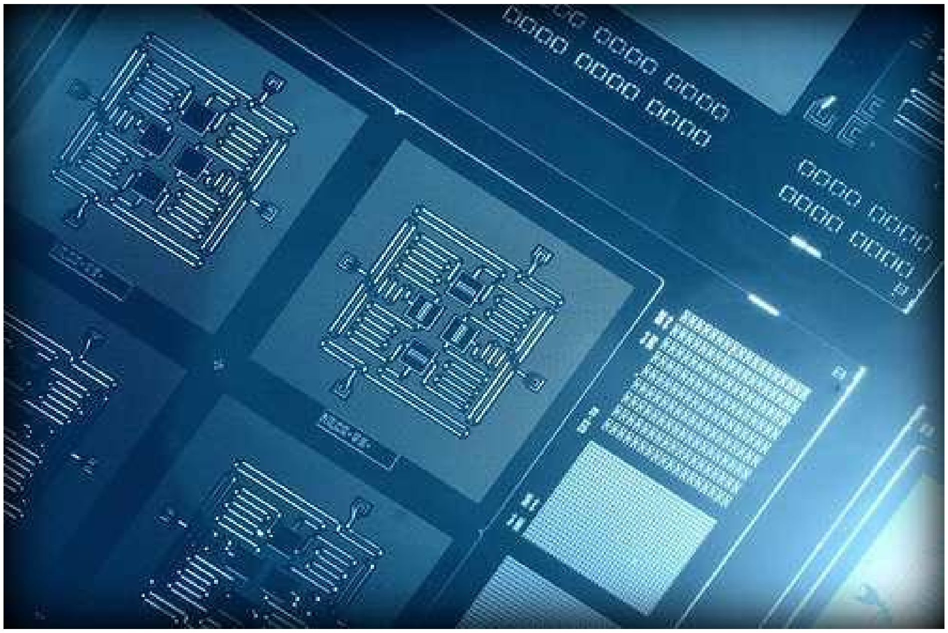


Figure 1. Proposed experimental setup for the generation of a scalable square-lattice cluster state. Light propagates (right to left) from the optical parametric oscillator (OPO) of free spectral range, ??, and mode linewidth, d?. The OPO has two pumps that are offset symmetrically from the center frequency (2?0). The principal axes of the OPO's nonlinear crystal are denoted X, Y, and Z (OPO light propagates along the X direction and is polarized along the Y or Z direction). PBS: Polarizing beam splitter. BS: Beam splitter. HWP: Half-wave plate (rotated at angle ?). The time delays between the two arms of each Mach-Zehnder interferometer (MZI) are indicated (cis the speed of light). In particular, the ‘musical score’ condition (dt»d?- 1) is essential to the definition of the time bins, of duration dt. The obtained entanglement graphs are depicted in (a)–(d), in the lower half of the figure, ranging from initial entanglement pairs (a) to a fully fledged square lattice (d). In these graphs, the frequency labels of the qumodes run vertically and the time bins (t) run in the horizontal direction.

In summary, we demonstrated that our current, record-size, prototype quantum computing processors can be weaved into a hybrid time-frequency square lattice cluster state suitable for universal quantum computing. Until now, these processors have been scalable either in frequency or in time, but not in a universal manner because they are unidimensional. It is important to emphasize that the experimental implementation of our proposed approach merely requires putting together existing time- and frequency-domain technologies. In our future work we will address quantum processing in earnest. We will thus focus individually on measurement of, and feedforward on, all qumodes, and on the implementation of quantum error correction.

[9]

Scientists achieve critical steps to building first practical quantum computer



Layout of IBM's four superconducting quantum bit device. Using a square lattice, IBM is able to detect both types of quantum errors for the first time. This is the best configuration to add more qubits to scale to larger systems.

With Moore's Law expected to run out of steam, quantum computing will be among the inventions that could usher in a new era of innovation across industries.
Quantum computers promise to open up new capabilities in the fields of optimization and simulation simply not possible using today's computers. If a quantum computer could be built with just 50 quantum bits (qubits), no combination of today's TOP500 supercomputers could successfully outperform it.

The IBM breakthroughs, described in the April 29 issue of the journal Nature Communications, show for the first time the ability to detect and measure the two types of quantum errors (bit-flip and phase-flip) that will occur in any real quantum computer. Until now, it was only possible to address one type of quantum error or the other, but never both at the same time. This is a necessary step toward quantum error correction, which is a critical requirement for building a practical and reliable large-scale quantum computer.

IBM's novel and complex quantum bit circuit, based on a square lattice of four superconducting qubits on a chip roughly one-quarter-inch square, enables both types of quantum errors to be detected at the same time. By opting for a square-shaped design versus a linear array – which prevents the detection of both kinds of quantum errors simultaneously – IBM's design shows the best potential to scale by adding more qubits to arrive at a working quantum system.

"Quantum computing could be potentially transformative, enabling us to solve problems that are impossible or impractical to solve today," said Arvind Krishna, senior vice president and director of IBM Research. "While quantum computers have traditionally been explored for cryptography, one area we find very compelling is the potential for practical quantum systems to solve problems in physics and quantum chemistry that are unsolvable today. This could have enormous potential in materials or drug design, opening up a new realm of applications."

For instance, in physics and chemistry, quantum computing could allow scientists to design new materials and drug compounds without expensive trial and error experiments in the lab, potentially speeding up the rate and pace of innovation across many industries.

For a world consumed by Big Data, quantum computers could quickly sort and curate ever larger databases as well as massive stores of diverse, unstructured data. This could transform how people make decisions and how researchers across industries make critical discoveries.

One of the great challenges for scientists seeking to harness the power of quantum computing is controlling or removing quantum decoherence – the creation of errors in calculations caused by interference from factors such as heat, electromagnetic radiation, and material defects. The errors are especially acute in quantum machines, since quantum information is so fragile.

"Up until now, researchers have been able to detect bit-flip or phase-flip quantum errors, but never the two together. Previous work in this area, using linear arrangements, only looked at bit-flip errors offering incomplete information on the quantum state of a system and making them inadequate for a quantum computer," said Jay Gambetta, a manager in the IBM Quantum Computing Group. "Our four qubit results take us past this hurdle by detecting both types of quantum errors and can be scalable to larger systems, as the qubits are arranged in a square lattice as opposed to a linear array."

The work at IBM was funded in part by the IARPA (Intelligence Advanced Research Projects Activity) multi-qubit-coherent-operations program.

Detecting quantum errors

The most basic piece of information that a typical computer understands is a bit. Much like a beam of light that can be switched on or off, a bit can have only one of two values: "1" or "0". However, a quantum bit (qubit) can hold a value of 1 or 0 as well as both values at the same time, described as superposition and simply denoted as "0+1". The sign of this superposition is important because both states 0 and 1 have a phase relationship to each other. This superposition property is what allows quantum computers to choose the correct solution amongst millions of possibilities in a time much faster than a conventional computer.

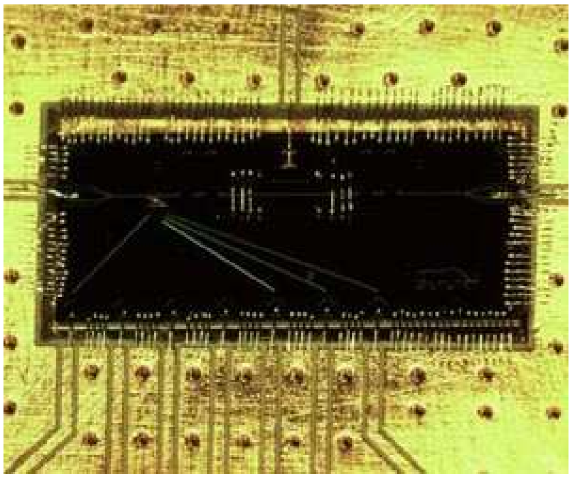
Two types of errors can occur on such a superposition state. One is called a bit-flip error, which simply flips a 0 to a 1 and vice versa. This is similar to classical bit-flip errors and previous work has showed how to detect these errors on qubits. However, this is not sufficient for quantum error correction because phase-flip errors can also be present, which flip the sign of the phase relationship between 0 and 1 in a superposition state. Both types of errors must be detected in order for quantum error correction to function properly.

Quantum information is very fragile because all existing qubit technologies lose their information when interacting with matter and electromagnetic radiation.
Theorists have found ways to preserve the information much longer by spreading information across many physical qubits. "Surface code" is the technical name for a specific error correction scheme

which spreads quantum information across many qubits. It allows for only nearest neighbor interactions to encode one logical qubit, making it sufficiently stable to perform error-free operations.

The IBM Research team used a variety of techniques to measure the states of two independent syndrome (measurement) qubits. Each reveals one aspect of the quantum information stored on two other qubits (called code, or data qubits). Specifically, one syndrome qubit revealed whether a bit-flip error occurred to either of the code qubits, while the other syndrome qubit revealed whether a phase-flip error occurred. Determining the joint quantum information in the code qubits is an essential step for quantum error correction because directly measuring the code qubits destroys the information contained within them. [8]

Next important step toward quantum computer



When facing big challenges, it is best to work together. In a team, the individual members can contribute their individual strengths - to the benefit of all those involved. One may be an absent-minded scientist who has brilliant ideas, but quickly forgets them. He needs the help of his conscientious colleague, who writes everything down, in order to remind the scatterbrain about it later. It's very similar in the world of quanta.

There the so-called quantum dots (abbreviated: qDots) play the role of the forgetful genius. Quantum dots are unbeatably fast, when it comes to disseminating quantum information. Unfortunately, they forget the result of the calculation just as quickly - too quickly to be of any real use in a quantum computer.

In contrast, charged atoms, called ions, have an excellent memory: They can store quantum information for many minutes. In the quantum world, that is an eternity.

They are less well suited for fast calculations, however, because the internal processes are comparatively slow.

The physicists from Bonn and Cambridge have therefore obliged both of these components, qDots and ions, to work together as a team. Experts speak of a hybrid system, because it combines two completely different quantum systems with one another.

Absent-minded qDots

qDots are considered the great hopes in the development of quantum computers. In principle, they are extremely miniaturized electron storage units. qDots can be produced using the same techniques as normal computer chips. To do so, it is only necessary to miniaturize the structures on the chips until they hold just one single electron (in a conventional PC it is 10 to 100 electrons).

The electron stored in a qDot can take on states that are predicted by quantum theory. However, they are very short-lived: They decay within a few picoseconds (for illustration: in one picosecond, light travels a distance of just 0.3 millimeters).

This decay produces a small flash of light: a photon. Photons are wave packets that vibrate in a specific plane - the direction of polarization. The state of the qDots determines the direction of polarization of the photon. "We used the photon to excite an ion", explains Prof. Dr. Michael Kohl from the Institute of Physics at the University of Bonn. "Then we stored the direction of polarization of the photon".

Conscientious ions

To do so, the researchers connected a thin glass fiber to the qDot. They transported the photon via the fiber to the ion many meters away. The fiberoptic networks used in telecommunications operate very similarly. To make the transfer of information as efficient as possible, they had trapped the ion between two mirrors. The mirrors bounced the photon back and forth like a ping pong ball, until it was absorbed by the ion.

"By shooting it with a laser beam, we were able to read out the ion that was excited in this way", explains Prof. Kohl. "In the process, we were able to measure the direction of polarization of the previously absorbed photon". In a sense then, the state of the qDot can be preserved in the ion - theoretically this can be done for many minutes. [7]

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]

Researchers have developed the first silicon quantum computer building blocks that can process data with more than 99 percent accuracy, overcoming a major hurdle in the race to develop reliable quantum computers.

Researchers from the University of New South Wales (UNSW) in Australia have achieved a huge breakthrough in quantum computing - they've created two kinds of silicon quantum bit, or qubits, the building blocks that make up any quantum computer, that are more than 99 percent accurate.

The postdoctoral researcher who was lead author on Morello's paper explained in the press release: "The phosphorus atom contains in fact two qubits: the electron, and the nucleus. With the nucleus in particular, we have achieved accuracy close to 99.99 percent. That means only one error for every 10,000 quantum operations."

Both the breakthroughs were achieved by embedding the atoms in a thin layer of specially purified silicon, which contains only the silicon-28 isotope. Naturally occurring silicon is magnetic and therefore disturbs the quantum bit, messing with the accuracy of its data processing, but silicon-28 is perfectly non-magnetic. [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]

Conclusions

Because these qubits can be designed and manufactured using standard silicon fabrication techniques, IBM anticipates that once a handful of superconducting qubits can be manufactured reliably and repeatedly, and controlled with low error rates, there will be no fundamental obstacle to demonstrating error correction in larger lattices of qubits. [8]

This success is an important step on the still long and rocky road to a quantum computer. In the long term, researchers around the world are hoping for true marvels from this new type of computer: Certain tasks, such as the factoring of large numbers, should be child's play for such a computer. In contrast, conventional computers find this a really tough nut to crack. However, a quantum computer displays its talents only for such special tasks: For normal types of basic computations, it is pitifully slow. [7]

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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