# Faster Quantum Information

*New theoretical work shows how much faster quantum information can travel through a system than classical information. [25]*

*Characterising quantum channels with non-separable states of classical light the researchers demonstrate the startling result that sometimes Nature cannot tell the difference between particular types of laser beams and quantum entangled photons. [24]*

*Physicists at Princeton University have revealed a device they've created that will allow a single electron to transfer its quantum information to a photon. [23]*

*A strong, short light pulse can record data on a magnetic layer of yttrium iron garnet doped with Co-ions. This was discovered by researchers from Radboud University in the Netherlands and Bialystok University in Poland. The novel mechanism outperforms existing alternatives, allowing the fastest read-write magnetic recording accompanied by unprecedentedly low heat load. [22]*

*It goes by the unwieldy acronym STT-MRAM, which stands for spin-transfer torque magnetic random access memory. [21]*

*Memory chips are among the most basic components in computers. The random access memory is where processors temporarily store their data, which is a crucial function. Researchers from Dresden and Basel have now managed to lay the foundation for a new memory chip concept. [20]*

*Researchers have built a record energy-efficient switch, which uses the interplay of electricity and a liquid form of light, in semiconductor microchips. The device could form the foundation of future signal processing and information technologies, making electronics even more efficient. [19]*

*The magnetic structure of a skyrmion is symmetrical around its core; arrows indicate the direction of spin. [18]*

*According to current estimates, dozens of zettabytes of information will be stored electronically by 2020, which will rely on physical principles that facilitate the use of single atoms or molecules as basic memory cells. [17]*

*EPFL scientists have developed a new perovskite material with unique properties that can be used to build next-generation hard drives. [16]*

*Scientists have fabricated a superlattice of single-atom magnets on graphene with a density of 115 terabits per square inch, suggesting that the configuration could lead to next-generation storage media. [15]*

*Now a researcher and his team at Tyndall National Institute in Cork have made a 'quantum leap' by developing a technical step that could enable the use of quantum computers sooner than expected. [14]*

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

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

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

*Optical photons would be ideal carriers to transfer quantum information over large distances. Researchers envisage a network where information is processed in certain nodes and transferred between them via photons. [9]*

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

*In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods.*

*The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the Wave-Particle Duality and the electron's spin also, building the Bridge between the Classical and Quantum Theories.*

*The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate and the Weak and Strong Interactions by the diffraction patterns. The Weak Interaction changes the diffraction patterns by moving the electric charge from one side to the other side of the diffraction pattern, which violates the CP and Time reversal symmetry.*

*The diffraction patterns and the locality of the self-maintaining electromagnetic potential explains also the Quantum Entanglement, giving it as a natural part of the Relativistic Quantum Theory and making possible to build the Quantum Computer with the help of Quantum Information.*

## Contents


Preface ... 5

Synopsis: Quantum Signals Outpace Classical Ones ... 5

Physicists show that real-time error correction in quantum communications is possible ... 6

- Classical and quantum worlds ... 6
- Real-time quantum error correction is possible ... 6
- Classically entangled light ... 7
- Fast and secure data transfer over real-world link ... 7

Now Quantum Computers Can Send Information Using a Single Particle of Light ... 8

Magnetic recording with light and no heat on garnet ... 8

- Exotic idea does work ... 9
- Spin-orbit interaction ... 9
- Applicable in data centres and super computers ... 9

Engineers work on promising new memory technology ... 10

- Nanomagnets ... 10
- Spin transfer ... 11

Random access memory on a low energy diet: Researchers develop basis for a novel memory chip 11

- Electrical voltage instead of current ... 12

Liquid light switch could enable more powerful electronics ... 12

Investigations of the skyrmion Hall effect reveal surprising results ... 14

New ultra-high density optical storage technology ... 15

A new perovskite could lead the next generation of data storage ... 16

Superlattice of single-atom magnets aims for ultimate limit of high-density data storage ... 17

Quantum dot LEDs that can produce entangled photons ... 18

Team demonstrates large-scale technique to produce quantum dots ... 19

Superfast light source made from artificial atom ... 20

- Quantum speed up ... 20
- Increasing the light-matter interaction ... 21

Single-photon source is efficient and indistinguishable ... 21

- Exciting dots ... 21

Quantum sandwich ...... 22
Semiconductor quantum dots as ideal single-photon source ...... 22
Noise in the semiconductor ...... 23
How to Win at Bridge Using Quantum Physics ...... 23
Quantum Information ...... 23
Heralded Qubit Transfer ...... 24
Quantum Teleportation ...... 24
Quantum Computing ...... 25
Quantum Entanglement ...... 25
The Bridge ...... 26
Accelerating charges ...... 26
Relativistic effect ...... 26
Heisenberg Uncertainty Relation ...... 26
Wave – Particle Duality ...... 26
Atomic model ...... 27
The Relativistic Bridge ...... 27
The weak interaction ...... 27
The General Weak Interaction ...... 28
Fermions and Bosons ...... 29
Van Der Waals force ...... 29
Electromagnetic inertia and mass ...... 29
Electromagnetic Induction ...... 29
Relativistic change of mass ...... 29
The frequency dependence of mass ...... 29
Electron – Proton mass rate ...... 29
Gravity from the point of view of quantum physics ...... 30
The Gravitational force ...... 30
The Higgs boson ...... 31
Higgs mechanism and Quantum Gravity ...... 31
What is the Spin? ...... 31
The Graviton ...... 32
Conclusions ...... 32
References ...... 32

Author: George Rajna

## Preface

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

Australian engineers detect in real-time the quantum spin properties of a pair of atoms inside a silicon chip, and disclose new method to perform quantum logic operations between two atoms. [5]

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently – instead, a quantum state may be given for the system as a whole. [4]

I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

## Synopsis: Quantum Signals Outpace Classical Ones

Rumors and bad news spread quickly, but they could travel even faster if they were quantized. A new theoretical work explores the limits of this quantum speedup in a model system based on computational grids called cellular automata. The authors show that quantum signals can initially travel much faster through the grids than classical signals. However, for time-symmetric cases (when forward signal speed equals backward speed), the quantum advantage eventually disappears.

A well-known example of quantum speedup is in random walks. In the classical case, the walker travels, on average, a distance proportional to the square root of the time elapsed. A quantum walker, by contrast, benefits from the phenomenon of quantum superposition that allows it to travel at a faster rate (the distance grows linearly with time).

Researchers from France and Germany investigated the quantum speedup for nonrandom systems. As a representative case, they chose cellular automata grids, which evolve based on well-defined rules and can model hydrodynamical and other physical systems. Each cell in the grid has a value, which is computed during each time step using the values of cells in a local neighborhood. The size of this neighborhood determines the speed with which information (concerning a change in the value of one cell, for example) travels through the grid. The researchers showed that such signals can travel faster if cells are allowed to be in quantum superpositions—effectively increasing their neighborhood size. This speedup is most prominent in the initial steps. As time wears on, the quantum speed approaches a limit that depends on how fast classical signals travel backwards in time.

This research is published in Physical Review A. [25]

## Physicists show that real-time error correction in quantum communications is possible

Nature Physics today, Monday, 23 January 2017, published online the research by a team led by physicists from the School of Physics at Wits University. In their paper titled: Characterising quantum channels with non-separable states of classical light the researchers demonstrate the startling result that sometimes Nature cannot tell the difference between particular types of laser beams and quantum entangled photons.

In essence, the research show that sometimes Nature cannot tell the difference between the quantum and the classical (or real) worlds, and that a grey area does exist between the two worlds called classical entanglement.

### Classical and quantum worlds

Present communication systems are very fast, but not fundamentally secure. To make them secure researchers use the laws of Nature for encoding by exploiting the quirky properties of the quantum world, such as in the case of the use of Quantum Key Distribution (QKD) for secure communication.

"Quantum" refers to the small, and in the photonics world this means one photon - a single particle of light. The rules of the quantum world are vastly different from that of the classical world, and experiments are traditionally much harder due to the difficulty in handling just a few photons.

"In the classical world our intuition holds true. There are no surprises and experiments can be done with many photons (billions and billions of them), such as laser light," explains Professor Andrew Forbes, team leader of the collaboration and Distinguished Professor in the School of Physics where he heads up the Wits Structured Light Laboratory.

"But not so in the quantum world, where things are never quite as they seem. Here waves sometimes look like particles, particles like waves, and measurements change the properties of the very thing you are trying to measure."

### Real-time quantum error correction is possible

Now researchers have shown that there is a grey area where Nature cannot tell the difference between the classical and the quantum. This opens the possibility of first performing quantum experiments with a type of classical light called "classically entangled" light.

For example, establishing a secure quantum communication link over long distance is very challenging: "Quantum links (as in fibre optics) using patterns of light languish at short distances precisely because there is no way to protect the link against noise (interference from, for instance, fog or a bend in a cable) without detecting the photons. Yet, once they are detected their usefulness is destroyed," says Forbes.

This catch 22 situation has been a seemingly insurmountable obstacle. Now the team has shown that this can be overcome using classical (many photon) light fields, enabling real-time quantum error correction.

By preparing and sending a so-called "classically entangled" beam the team could show that this was identical to sending a quantum state. This means that the observed quantum entanglement decay due to noise in the link can be reversed, paving the way for major advances in secure quantum links in fibre and free-space.

"We showed for the first time that classical light can be used to analyse a quantum link, acting as a direct equivalent to the behavior of the quantum state," says Bienvenu Ndagano, lead author and PhD student at Wits University.

"Not similar, or mimicking, but equivalent. To show this, we exploited a particular type of laser beam, called vector beams, that have the property of being non-separable and sometimes called 'classically entangled'."

Ndagano explains that the quintessential property of quantum entanglement is the non-separability of the state, meaning that one part of the system cannot be separated from the other. "But non-separability is not unique to the quantum world: you can find it in weather maps where the locations on the map and the temperatures at those locations can't be separated."

## Classically entangled light

More intriguingly, classical vector beams have this property too, which the team calls "classically entangled" light.

Says Forbes, "What we asked was: does this mean that classical light can be used in quantum systems - a grey area between the two worlds that we call classical entanglement?".

"The notion of classical entanglement is hotly contested in the physics community with some arguing that it is merely a mathematical construct," says Thomas Konrad (UKZN), co-author on the paper. "This work shows that there is physical meaning to it too, and we offer the first side-by-side data of the equivalence of classical and quantum entanglement".

Previously, to fix an error in the quantum state used for secure communication would mean measuring the photon sent, which in turn would mean losing the information that one was trying to send.

This work allows for long distance quantum links to be established and tested with classically entangled light: as there is no shortage of photons in the classical light, all the measurements needed to fix the errors in the quantum state can be done in real-time without destroying the quantum information.

Thus, real-time error correction is possible as you can run experiments in the classical world that will tell you how to fix the error in the quantum world.

## Fast and secure data transfer over real-world link

The team are working on packing as much information into photons using patterns of light as a means to encode the information. Since there are an unlimited number of patterns, the amount of information that can be sent securely is also in principle at least, unlimited.

While all patterns are equivalent in terms of information capacity, this work suggests that the choice of pattern also plays an important role in analysing and correcting the errors experienced by passing over the link.

"By working in this grey area between the classical and the quantum we can show fast and secure data transfer over real-world links," says Forbes. [24]

## Now Quantum Computers Can Send Information Using a Single Particle of Light

Physicists at Princeton University have revealed a device they've created that will allow a single electron to transfer its quantum information to a photon. This is a revolutionary breakthrough for the team as it gets them one step closer to producing the ultimate quantum computer. The device is the result of five years worth of research and could accelerate the world of quantum computing no end.

Xiao Mi, a graduate student in Princeton's Department of Physics, says, "We now have the ability to transmit the quantum state to a photon. This has never been done in a semiconductor device because the quantum state was lost before it could transfer its information." The way in which the device works is by trapping an electron and photon within a device built by HRL Laboratories and owned by Boeing and General Motors. The semiconducting chip is made up of several layers of silicon and silicon-germanium, and across the top are a number of nanowires that are used to deliver energy to the chip.

Quantum computing brings with it a whole range of advantages; the main one being its capability to calculate many problems simultaneously resulting in much faster computing than anything we're used to. Jason Petta, professor of physics at Princeton, said, "In our device, the state of the qubit is encoded in the position of the electron. The electron is trapped in a double well potential where the electron can occupy the left well, the right well, or be in a superposition state: both left and right at the same time. The information is therefore stored in the position of a single electron."

The researchers discovered the best way for them to pass information between electrons without destroying them in the process was to use photons as they're less sensitive to environmental factors and would be perfect for helping to form the circuits for a quantum computer. Petta goes on to say," Just like in human interactions, to have good communication a number of things need to work out – it helps to speak the same language and so forth. We are able to bring the energy of the electronic state into resonance with the light particle so that the two can talk to each other." The researchers will continue to do further work with the device to fine tune it to allow greater control over the transferring of information between qubits. [23]

## Magnetic recording with light and no heat on garnet

A strong, short light pulse can record data on a magnetic layer of yttrium iron garnet doped with Co-ions. This was discovered by researchers from Radboud University in the Netherlands and Bialystok University in Poland. The novel mechanism outperforms existing alternatives, allowing the fastest read-write magnetic recording accompanied by unprecedentedly low heat load. The research was reported in Nature on January 18 2017.

Reliable, cheap and quick data recording will be as crucial to 21st century economics as oil was to that of the 20th century. Magnetic recording performs rather well in that respect, but data centres become overheated due to the sharp rise in demand of cloud storage – consider the scale of Facebook and WhatsApp traffic. A lot of energy is needed to cool server processors. heat assisted magnetic recording, or HAMR, the latest innovation in magnetic recording, will not solve this problem. On the contrary, it uses the heat of a laser pulse to speed up the recording process. For this reason, super-fast magnetic recording that produces no heat and does not need electromagnets is the holy grail of current fundamental and applied research on magnetism.

## Exotic idea does work

Researchers from Radboud University have been experimenting with ways to use the energy of a light pulse to manipulate magnets for more than a decade. Professor Theo Rasing and his colleagues published their first results in a 2007 article in the international journal Science.

The problem with their initial findings was that the mechanism of the recording relied on laser-induced heating that reached temperatures close to the so-called Curie temperature, above which the magnetic order is destroyed. The recording via heating and partial destruction of the magnetic order seriously hampered potential applications. Heating negatively affects the thermal stability of a recording medium, limits the repetition frequency by the cooling time, and limits the recording density due to heat diffusion.

## Spin-orbit interaction

Tackling the heating problem requires a medium with low optical absorption. For metals with a lot of free electrons, the absorption of light—and thus heating of the material—is unavoidable. It means that in order to reduce the heating, a dielectric material is required. For this study, the scientists chose yttrium iron garnet (YIG) – one of the model magnetic dielectrics in fundamental and applied research. It is impossible to record information through light on normal YIG. But to increase its sensitivity to optical excitation, the scientists doped it with Co-ions. Co-ions are known for the strong coupling of magnetic moments to the orbital motion of electron (so-called spin-orbit interaction). Light can effectively change orbital motion of the electrons in the ions and thus affect magnetism. Experiments fully met the expectations of the scientists. They found that in the Co-substituted garnet film, a single linearly polarized femtosecond laser pulse promotes switching of spins between different states.

"By changing the polarization of the laser pulse, we deterministically steer the net magnetization in the garnet—we write 0 and 1 magnetic bits at will," says physicist Alexey Kimel from Radboud University. "This mechanism outperforms existing alternatives, allowing the fastest ever magnetic write-read recording event, lower than twenty pico-seconds, accompanied by unprecedentedly low heat load." Kimel had trouble getting funding for this project because his idea was considered too exotic to work. The publication in Nature proves that he was right from the start.

## Applicable in data centres and super computers

Using light for magnetic switching on garnet films will probably not be applied in personal computers. "The technology gap between storing on metal and garnet crystal is too big," Alexey Kimel thinks. "But it could be an interesting option for the big data warehouses of Google and Facebook and the like. Another possible use could be data recording at very low temperatures. Superconducting electronics and quantum computers lack a fast memory system that can record at temperatures below 10 Kelvin (-263 degrees Celsius). Up until now, this was a serious obstacle for superconducting computing." [22]

## Engineers work on promising new memory technology

Today's computers often use as many as four different kinds of memory technology, from the hard drive to the memory chips, each with its own strengths and weaknesses. A new memory technology may be poised to disrupt this landscape, however, with a unique combination of features. It goes by the unwieldy acronym STT-MRAM, which stands for spin-transfer torque magnetic random access memory.

"All other memory technologies are good at some things and not so good at others. People are hoping that STT-MRAM can be good at everything," said electrical engineer Holger Schmidt, the Kapany Professor of Optoelectronics at UC Santa Cruz.

As one of 15 partners in the Samsung Global MRAM Innovation program, Schmidt's lab is collaborating with Samsung researchers to help develop this emerging memory technology. With his expertise in optoelectronics, Schmidt is using optical techniques based on ultra-short laser pulses to study preproduction prototype devices from Samsung. His assessments are helping the company optimize their materials and fabrication processes.

### Nanomagnets

STT-MRAM stores information in the magnetic states of tiny magnetic elements or "nanomagnets" less than 100 nanometers across. Unlike other magnetic storage technologies, such as hard drives with their spinning disks and magnetic read-write heads, STT-MRAM devices have no moving parts because they use electric current to read and write data. Although current implementations still have plenty of room for improvement, the technology offers the potential for high-speed, high-density, energy-efficient memory that is nonvolatile, meaning stored information is not lost when the power is cut off.

Several key advances in physics and materials science over the past 20 years have led to the development of STT-MRAM and other so-called spintronic technologies. While electronic devices are based on the movement of electrical charges, spintronics exploits another property of electrons called spin. Spin is one of those bizarre concepts of quantum mechanics without a direct equivalent in our macroscopic world. Suffice it to say that electrons behave as if they were spinning, producing a small magnetic moment (like a tiny bar magnet with north and south poles) that can interact with other electrons and atoms in a material.

The nanomagnets in an STT-MRAM device, called spin valves or magnetic tunnel junctions, have two magnetic layers separated by a thin barrier through which electric current can flow. When the spins in the two magnetic layers are aligned, resistance is low, and if the two layers have opposite spins resistance is high, providing two readable and switchable states to represent 0 and 1 in the binary logic of computers.

## Spin transfer

The ability to switch the state of a spin valve with an electric current was a critical innovation. A polarized current in which the spins of the electrons are aligned can transfer that spin state to one of the magnetic layers as it passes through, a phenomenon called spin-transfer torque (STT).

STT-MRAM chips for niche applications are just beginning to reach the market, and dozens of companies are working to optimize the technology for use in consumer electronics.

According to Schmidt, one of the challenges is to operate the chips with as little power as possible so they don't heat up too much. How much current it takes to switch a nanomagnet depends on damping, or how long it takes to settle down into a new spin state, he explained. Measuring damping parameters in an array of nanomagnets is extremely challenging, but Schmidt's lab is able to do this using short laser pulses. He and his collaborators, led by graduate student and first author Mike Jaris, reported their latest findings in a paper published in Applied Physics Letters.

"We were able to extract damping measurements from prototype devices and show the effects of the fabrication process on the material properties of the nanomagnets," Schmidt said.

The collaboration with Samsung has been exciting for his lab, he said, giving his students the opportunity to work at the cutting edge of an emerging technology. "It's a completely different type of memory, and I expect to see it used in more applications over the next few years," he said. [21]

# Random access memory on a low energy diet: Researchers develop basis for a novel memory chip

Memory chips are among the most basic components in computers. The random access memory is where processors temporarily store their data, which is a crucial function. Researchers from Dresden and Basel have now managed to lay the foundation for a new memory chip concept. It has the potential to use considerably less energy than the chips produced to date - this is important not only for mobile applications but also for big data computing centers. The results are presented in the latest volume of the scientific journal Nature Communications.

The purely electrical memory chips that are commonly used today have a significant disadvantage: "This memory is volatile and its state must be continuously refreshed," says Dr. Tobias Kosub, first author of the study and post-doctoral researcher at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR). "This requires quite a lot of energy." The consequences can be seen, for example, at large computing centers. On the one hand, their electricity bills rise with increased computing power. On the other hand, the chips increasingly heat up based on their energy consumption. The data centers are finding it increasingly difficult to dissipate this heat. Some Cloud operators go as far as to set up their server farms in cold regions.

There is an alternative to these electrical memory chips. MRAMs save data magnetically and therefore do not require constant refreshing. They do, however, require relatively large electrical currents to write the data to memory, which reduces reliability: "They threaten to wear out too quickly and break down if disruptions occur during the writing or reading process," Kosub says.

## Electrical voltage instead of current

The scientific world has therefore been working on MRAM alternatives for quite a while. One material class called "magnetoelectric antiferromagnets" appears particularly promising. These magnets are activated by an electrical voltage rather than by a current. "These materials cannot be easily controlled," explains HZDR group leader Dr. Denys Makarov. "It is difficult to write data to them and read them out again." So far it has been assumed that these magnetoelectric antiferromagnets can only be read indirectly via ferromagnets, which, however, negates many of the advantages. The goal is therefore to produce a purely antiferromagnetic magnetoelectric memory (AF-MERAM).

This is precisely what the research teams from Dresden and Basel have now managed to do. They developed a novel AF-MERAM prototype based on a thin layer of chromium oxide. This is inserted - like a sandwich filling - between two nanometer-thin electrodes. If a voltage is applied to these electrodes, the chromium oxide "flips" into a different magnetic state - and the bit is written. The key is that a few volts are sufficient. "In contrast to other concepts, we could reduce the voltage by a factor of fifty," says Kosub. "This allows us to write a bit without excessive energy consumption and heating." A particular challenge was the ability to read out the written bit again.

In order to do so, the physicists attached a nanometer-thin platinum layer on top of the chromium oxide. The platinum enables the readout through a special electrical phenomenon - the Anomalous Hall Effect. The actual signal is very small and is superimposed by interference signals. "We could, however, develop a method that suppressed the storm of interference, allowing us to obtain the useful signal," Makarov describes. "This was, in fact, the breakthrough." The results look very promising according to Prof. Oliver G. Schmidt of the Leibniz Institute for Solid State and Materials Research Dresden, which also participated in the study: "It will be exciting to pursue how this new approach will position itself with regard to established silicium-technology." Now the researchers are about to develop the concept further.

"The material is thus far working at room temperature, but only within a narrow window," says Kosub. "We want to considerably expand the range by selectively altering the chromium oxide." To achieve this, the colleagues from the Swiss Nanoscience Institute and the Department of Physics at the University of Basel have made an important contribution. Their new investigation method provides images of the magnetic properties of the chromium oxide for the first time with nanoscale resolution. The experts now aim to integrate several memory elements on a single chip. So far, only a single element was realized, which can store merely one bit. The next step, a crucial one towards possible applications, is to construct an array of several elements. "In principle, such memory chips could be produced using standard methods employed by computer manufacturers," says Makarov. "This is one of the reasons the industry has shown great interest in such components." [20]

# Liquid light switch could enable more powerful electronics

Researchers have built a record energy-efficient switch, which uses the interplay of electricity and a liquid form of light, in semiconductor microchips. The device could form the foundation of future signal processing and information technologies, making electronics even more efficient.

We’re reaching the limits of how small we can make transistors, and electronics based on liquid light could be a way of increasing the power and efficiency of the electronics we rely on.

Researchers have built a miniature electro-optical switch which can change the spin – or angular momentum – of a liquid form of light by applying electric fields to a semiconductor device a millionth of a metre in size. Their results, reported in the journal Nature Materials, demonstrate how to bridge the gap between light and electricity, which could enable the development of ever faster and smaller electronics.

There is a fundamental disparity between the way in which information is processed and transmitted by current technologies. To process information, electrical charges are moved around on semiconductor chips; and to transmit it, light flashes are sent down optical fibres. Current methods of converting between electrical and optical signals are both inefficient and slow, and researchers have been searching for ways to incorporate the two.

In order to make electronics faster and more powerful, more transistors need to be squeezed onto semiconductor chips. For the past 50 years, the number of transistors on a single chip has doubled every two years – this is known as Moore’s law. However, as chips keep getting smaller, scientists now have to deal with the quantum effects associated with individual atoms and electrons, and they are looking for alternatives to the electron as the primary carrier of information in order to keep up with Moore’s law and our thirst for faster, cheaper and more powerful electronics.

The University of Cambridge researchers, led by Professor Jeremy Baumberg from the NanoPhotonics Centre, in collaboration with researchers from Mexico and Greece, have built a switch which utilises a new state of matter called a Polariton Bose-Einstein condensate in order to mix electric and optical signals, while using miniscule amounts of energy.

Polariton Bose-Einstein condensates are generated by trapping light between mirrors spaced only a few millionths of a metre apart, and letting it interact with thin slabs of semiconductor material, creating a half-light, half-matter mixture known as a polariton.

Putting lots of polaritons in the same space can induce condensation – similar to the condensation of water droplets at high humidity – and the formation of a light-matter fluid which spins clockwise (spin-up) or anticlockwise (spin-down). By applying an electric field to this system, the researchers were able to control the spin of the condensate and switch it between up and down states. The polariton fluid emits light with clockwise or anticlockwise spin, which can be sent through optical fibres for communication, converting electrical to optical signals.

“The polariton switch unifies the best properties of electronics and optics into one tiny device that can deliver at very high speeds while using minimal amounts of power,” said the paper’s lead author Dr Alexander Dreismann from Cambridge’s Cavendish Laboratory.

“We have made a field-effect light switch that can bridge the gap between optics and electronics,” said co-author Dr Hamid Ohadi, also from the Cavendish Laboratory. “We’re reaching the limits of how small we can make transistors, and electronics based on liquid light could be a way of increasing the power and efficiency of the electronics we rely on.”

While the prototype device works at cryogenic temperatures, the researchers are developing other materials that can operate at room temperature, so that the device may be commercialised. The other key factor for the commercialisation of the device is mass production and scalability. "Since this prototype is based on well-established fabrication technology, it has the potential to be scaled up in the near future," said study co-author Professor Pavlos Savvidis from the FORTH institute in Crete, Greece.

The team is currently exploring options for commercialising the technology as well as integrating it with the existing technology base.

The research is funded as part of a UK Engineering and Physical Sciences Research Council (EPSRC) investment in the Cambridge NanoPhotonics Centre, as well as the European Research Council (ERC) and the Leverhulme Trust. [19]

## Investigations of the skyrmion Hall effect reveal surprising results

Researchers at Johannes Gutenberg University Mainz (JGU) and the Massachusetts Institute of Technology (MIT) have made a breakthrough in the field of future magnetic storage devices. In March 2016, the international team investigated structures that could serve as magnetic-shift register or racetrack memory devices. This type of storage promises low access times, high information density, and low energy consumption. Now, the research team has achieved the billion-fold reproducible motion of special magnetic textures, so-called skyrmions, between different positions, a key process needed in magnetic shift registers, thereby taking a critical step toward the application of skyrmions in devices. The work was published in the research journal Nature Physics.

The experiments were carried out in specially designed thin film structures, i.e., vertically asymmetric multilayer devices exhibiting broken inversion symmetry, which stabilized special spin structures called skyrmions. Those structures are similar to a hair whorl, and are relatively difficult to destroy. This grants them a unique stability, which is another argument for the application of skyrmions in such spintronic devices.

Skyrmions can be shifted by electrical currents and feel a repulsive force from the edges of the magnetic track as well as from single defects in the wire. Thus, they can move relatively undisturbed through the track. This is a key property for racetrack devices, which are proposed to consist of static read and write heads, while the magnetic bits are shifted in the track. However, skyrmions do not only move parallel to the applied current, but also perpendicular to it. This leads to an angle between the skyrmion direction of motion and the current flow called the skyrmion Hall angle. This has been predicted theoretically. As a result, the skyrmions should move under this constant angle until they are repelled by the edge of the material and then keep a constant distance from it.

Scientists of JGU and MIT have now proved that the billion-fold reproducible displacement of skyrmions is, indeed, possible, and can be achieved with high velocities. Furthermore, the skyrmion Hall angle was investigated in detail. Surprisingly, it turned out to be dependent on the velocity of the skyrmions, which means that the components of the motion parallel and perpendicular to the current flow do not scale equally with the velocity of the skyrmions. This is not predicted in the conventional theoretical description of skyrmions. Part of the solution to this unexpected behavior could be the deformation of the skyrmion spin structure, calling for more theoretical effort to fully understand the properties of skyrmions.

"In highly competitive fields of research such as that on skyrmions, international cooperation with leading groups is a strategical advantage. Within only two years after the start of the collaboration with our colleagues from MIT, we have already published the second time together in a high-ranked Nature group journal. The MAINZ Graduate School of Excellence facilitates research stays of PhD students from the United States in Mainz and vice versa and therefore contributes significantly to international education and successful research in this field," said Professor Mathias Kläui of the JGU Institute of Physics, who is also Director of MAINZ. [18]

## New ultra-high density optical storage technology

According to current estimates, dozens of zettabytes of information will be stored electronically by 2020, which will rely on physical principles that facilitate the use of single atoms or molecules as basic memory cells. This can be done using lasers. However, existing methods of optical storage are limited to the diffraction limit (~500 nm), so the respective recording density is roughly ~1 Gb per square decimeter.

The limitation can be circumvented by the use of highly localized lasers that can manipulate the spatial orientation of single molecules. The expected storage capacity in this case is up to 1 Pb/dm2, which is approximately equal to 1 million standard DVDs. Regulating radiation beyond the diffraction limit with the help of optical nanoantennas and nanoresonators is the basis for three current research areas—refractory plasmonics, organic photovoltaics, and near-field optical memory. All of them are in development at the Nano Optics Lab of KFU headed by Associate Professor Sergey Kharintsev.

Thanks to subdiffraction localization and field enhancement of light, single-molecule detection technologies are emerging rapidly. Dr. Kharintsev's team has used this approach for near-field optical recording. Their research appeared in Nanoscale in November 2016. The authors proposed a new principle of optical storage based on tip-enhanced Raman scattering effect.

Localization of laser light is provided by an optical nanoantenna that is illuminated by a focused laser beam with radial and azimuthal polarization. This approach is based on optical anisotropy of azo-dye polymer films, as reported in ACS Photonics. The azo-dyes are orientated perpendicularly to the polarization direction under polarized light. This has proven to be a tricky achievement because near-field polarization depends on the geometry and material of the optical antenna.

Switching between radial and azimuthal polarization enables the recording of optical information in the azo-dye absorption band and reading beyond that band. The switching speed depends on the local mobility of the dyes in a glassy environment—a parameter critically dependent on the thickness of polymer film. The team plans to create a prototype of organic near-field optical memory of up 1 Pb/dm2 density. Advances in subdiffraction technology will be linked to laser beams with orbital momentum—such research may eventually increase storage density.

Optical disks with petabit capacity will change the efficiency and productivity of cloud services and data centers and disrupt the global storage market. The development of such storage is linked with energy-independent, high-speed memory technologies that aim to unite the advantages of random access memory and archive memory. Alternative memory types, such as quantum memory, spin-transfer torque memory, memristors, and ferroelectrical memory, are all still far from practical use. [17]

## A new perovskite could lead the next generation of data storage

EPFL scientists have developed a new perovskite material with unique properties that can be used to build next-generation hard drives.

As we generate more and more data, we need storage systems, e.g. hard drives, with higher density and efficiency. But this also requires materials whose magnetic properties can be quickly and easily manipulated in order to write and access data on them. EPFL scientists have now developed a perovskite material whose magnetic order can be rapidly changed without disrupting it due to heating. The work, which describes the first ever magnetic photoconductor, is published in Nature Communications.

The lab of Laszló Forró, in a project led by postdoc Bálint Náfrádi, synthesized a ferromagnetic photovoltaic material. Perovskite photovoltaics are gradually becoming a cheaper alternative to current silicon systems, drawing much interest from energy scientists. But this particular material, which is a modified version of perovskite, exhibits some unique properties that make it particularly interesting as a material to build next-generation digital storage systems.

Magnetism in material arises from the interactions of localized and moving electrons of the material; in a way, it is the result of competition between different movements of electrons. This means that the resulting magnetic state is wired in the material and it cannot be reversed without changing the structure of electrons in the material's chemistry or crystal structure. But an easy way to modify magnetic properties would be an enormous advantage in many applications such as magnetic data storage.

The new material that the EPFL scientists developed offers exactly that. "We have essentially discovered the first magnetic photoconductor," says Bálint Náfrádi. This new crystal structure combines the advantages of both ferromagnets, whose magnetic moments are aligned in a well-defined order, and photoconductors, where light illumination generates high density free conduction electrons.

The combination of the two properties produced an entirely new phenomenon: the "melting" of magnetization by photo-electrons, which are electrons that are emitted from a material when light hits it. In the new perovskite material, a simple red LED—much weaker than a laser pointer—is enough to disrupt, or "melt" the material's magnetic order and generate a high density of travelling electrons, which can be freely and continuously tuned by changing the light's intensity. The timescale for shifting the magnetic in this material is also very fast, virtually needing only quadrillionths of a second.

Though still experimental, all these properties mean that the new material can be used to build the next generation of memory-storage systems, featuring higher capacities with low energy demands. "This study provides the basis for the development of a new generation of magneto-optical data storage devices," says Náfrádi. "These would combine the advantages of magnetic storage—long-term stability, high data density, non-volatile operation and re-writability— with the speed of optical writing and reading." [16]

## Superlattice of single-atom magnets aims for ultimate limit of high-density data storage

Scientists have fabricated a superlattice of single-atom magnets on graphene with a density of 115 terabits per square inch, suggesting that the configuration could lead to next-generation storage media.

"Single-atom magnets represent the ultimate limit for ultrahigh-density magnetic storage devices," Stefano Rusponi, a physicist at the Ecole Polytechnique Fédérale de Lausanne (EPFL) and coauthor of the new research, told Phys.org. "So far, researchers have mainly focused on the magnetic properties of single atoms and small clusters randomly distributed on the supporting surfaces."

"In our new paper, we demonstrate the ability to realize a superlattice of single atoms having stable magnetization. This represents the first prototype of a storage media based on a single atom per bit."

As the researchers explained, a key challenge in using an array of atomic magnets as a data storage device is to ensure that the magnets are stable and do not interact with each other, since this could result in data loss.

To address this challenge, the research team, led by Professor Harald Brune at EPFL, took advantage of the good magnetic properties of dysprosium atoms, along with the properties of the graphene-iridium substrate.

Part of the reason for the highly stable magnetization is because of the lattice mismatch between graphene and iridium, which creates a periodic moiré pattern. This periodic pattern leads to an equidistant arrangement of the most favorable dysprosium adsorption sites.

When the dysprosium atoms are deposited onto the substrate at about 40 K, their surface diffusion is activated, which causes them to jump around on the surface. This motion allows them to reach the most favorable adsorption sites determined by the moiré pattern, so that they form a highly ordered array, with an average distance between atoms of just 2.5 nanometers.

Once assembled, the atoms' magnetic stability can be affected in a few ways, including by scattering with electrons and phonons on the surface, as well as by quantum tunneling of the magnetic states.

Fortunately, two of the beneficial properties of graphene are its very low electron and phonon densities, which protects the dysprosium atoms against scattering. In addition, the dysprosium atoms have a favorable magnetic ground state that protects against quantum tunneling of the magnetization. Both properties contribute to the high magnetic stability of the superlattice.

Measurements showed that the superlattice has a very large magnetic hysteresis—which is a measure of the irreversibility of a magnet—that outperforms the best dysprosium-based single-ion molecular magnets. The researchers explain that the high magnetic stability depends on all of the combined properties of the atoms and the graphene-iridium substrate, and that missing just one of these properties greatly reduces the stability.

One of the current drawbacks of the design is that the magnetic stability decreases at higher temperatures. In the future, the researchers plan to improve the superlattice's thermal stability, possibly by growing graphene on an insulating substrate.

"The magnetic stability of the dysprosium atoms is limited to temperatures below 10 K and is sensitive to contamination, thus requiring ultra-high vacuum conditions for our experiments," Rusponi said. "In the future, we plan to improve the performances of the single-atom magnet superlattice. First, we intend to increase the maximum temperature at which the magnetic stability survives by finding the optimum combination of single atom species and supporting substrate. Second, we intend to protect the superlattice with a capping layer preserving the properties of the magnetic atoms." [15]

## Quantum dot LEDs that can produce entangled photons

Quantum computing is heralded as the next revolution in terms of global computing. Google, Intel and IBM are just some of the big names investing millions currently in the field of quantum computing which will enable faster, more efficient computing required to power the requirements of our future computing needs.

Now a researcher and his team at Tyndall National Institute in Cork have made a 'quantum leap' by developing a technical step that could enable the use of quantum computers sooner than expected.

Conventional digital computing uses 'on-off' switches, but quantum computing looks to harness quantum state of matters—such as entangled photons of light or multiple states of atoms—to encode information. In theory, this can lead to much faster and more powerful computer processing, but the technology to underpin quantum computing is currently difficult to develop at scale.

Researchers at Tyndall have taken a step forward by making quantum dot light-emitting diodes (LEDs) that can produce entangled photons (whose actions are linked), theoretically enabling their use to encode information in quantum computing.

This is not the first time that LEDs have been made that can produce entangled photons, but the methods and materials described in the new paper have important implications for the future of quantum technologies, explains researcher Dr Emanuele Pelucchi, Head of Epitaxy and Physics of Nanostructures and a member of the Science Foundation Ireland-funded Irish Photonic Integration Centre (IPIC) at Tyndall National Institute in Cork.

"The new development here is that we have engineered a scalable array of electrically driven quantum dots using easily-sourced materials and conventional semiconductor fabrication technologies, and our method allows you to direct the position of these sources of entangled photons," he says.

"Being able to control the positions of the quantum dots and to build them at scale are key factors to underpin more widespread use of quantum computing technologies as they develop."

The Tyndall technology uses nanotechnology to electrify arrays of the pyramid-shaped quantum dots so they produce entangled photons. "We exploit intrinsic nanoscale properties of the whole "pyramidal" structure, in particular, an engineered self-assembled vertical quantum wire, which selectively injects current into the vicinity of a quantum dot," explains Dr Pelucchi.

"The reported results are an important step towards the realisation of integrated quantum photonic circuits designed for quantum information processing tasks, where thousands or more sources would function in unison."

"It is exciting to see how research at Tyndall continues to break new ground, particularly in relation to this development in quantum computing. The significant breakthrough by Dr Pelucchi advances our understanding of how to harness the opportunity and power of quantum computing and undoubtedly accelerates progress in this field internationally. Photonics innovations by the IPIC team at Tyndall are being commercialised across a number sectors and as a result, we are directly driving global innovation through our investment, talent and research in this area," said Dr Kieran Drain, CEO at Tyndall National Institute. [14]

## Team demonstrates large-scale technique to produce quantum dots

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

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

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

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

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

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

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

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

## Superfast light source made from artificial atom

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

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

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

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

### Quantum speed up

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

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

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

### Increasing the light-matter interaction

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

He adds that it is actually the temperature, which is only a few degrees above absolute zero, that limits how fast the light emissions can remain in their current experiments. In the long term, they will study the quantum dots at even lower temperatures, where the effects could be very dramatic. [12]

## Single-photon source is efficient and indistinguishable

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

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

### Exciting dots

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

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

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

### Quantum sandwich

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

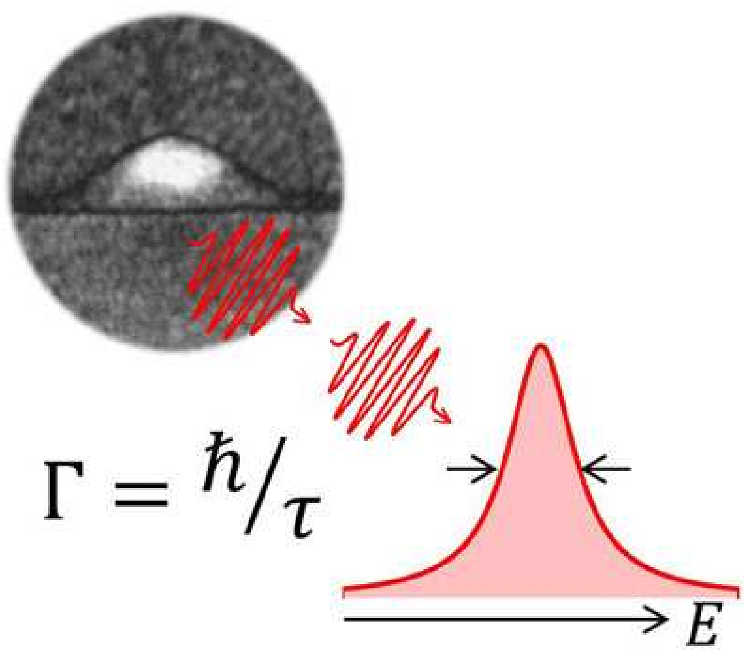
The micropillar is about 2.5 µm in diameter and about 10 µm tall, and it allowed the team to harness the "Purcell effect", whereby the rate of fluorescence is increased significantly when the emitter is placed in a resonant cavity.

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

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

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

## Semiconductor quantum dots as ideal single-photon source



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

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

### Noise in the semiconductor

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

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

## How to Win at Bridge Using Quantum Physics

Contract bridge is the chess of card games. You might know it as some stuffy old game your grandparents play, but it requires major brainpower, and preferably an obsession with rules and strategy. So how to make it even geekier? Throw in some quantum mechanics to try to gain a competitive advantage. The idea here is to use the quantum magic of entangled photons–which are essentially twins, sharing every property–to transmit two bits of information to your bridge partner for the price of one. Understanding how to do this is not an easy task, but it will help elucidate some basic building blocks of quantum information theory. It’s also kind of fun to consider whether or not such tactics could ever be allowed in professional sports. [6]

## Quantum Information

In quantum mechanics, quantum information is physical information that is held in the "state" of a quantum system. The most popular unit of quantum information is the qubit, a two-level quantum system. However, unlike classical digital states (which are discrete), a two-state quantum system can actually be in a superposition of the two states at any given time.

Quantum information differs from classical information in several respects, among which we note the following:

However, despite this, the amount of information that can be retrieved in a single qubit is equal to one bit. It is in the processing of information (quantum computation) that a difference occurs.

The ability to manipulate quantum information enables us to perform tasks that would be unachievable in a classical context, such as unconditionally secure transmission of information. Quantum information processing is the most general field that is concerned with quantum information. There are certain tasks which classical computers cannot perform "efficiently" (that is, in polynomial time) according to any known algorithm. However, a quantum computer can compute the answer to some of these problems in polynomial time; one well-known example of this is Shor's factoring algorithm. Other algorithms can speed up a task less dramatically - for example, Grover's search algorithm which gives a quadratic speed-up over the best possible classical algorithm.

Quantum information, and changes in quantum information, can be quantitatively measured by using an analogue of Shannon entropy. Given a statistical ensemble of quantum mechanical systems with the density matrix S, it is given by.

Many of the same entropy measures in classical information theory can also be generalized to the quantum case, such as the conditional quantum entropy. [7]

## Heralded Qubit Transfer

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

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

## Quantum Teleportation

Quantum teleportation is a process by which quantum information (e.g. the exact state of an atom or photon) can be transmitted (exactly, in principle) from one location to another, with the help of classical communication and previously shared quantum entanglement between the sending and receiving location. Because it depends on classical communication, which can proceed no faster than the speed of light, it cannot be used for superluminal transport or communication of classical bits. It also cannot be used to make copies of a system, as this violates the no-cloning theorem. Although the name is inspired by the teleportation commonly used in fiction, current technology provides no possibility of anything resembling the fictional form of teleportation. While it is possible to teleport one or more qubits of information between two (entangled) atoms, this has not yet been achieved between molecules or anything larger. One may think of teleportation either as a kind of transportation, or as a kind of communication; it provides a way of transporting a qubit from one location to another, without having to move a physical particle along with it.

The seminal paper first expounding the idea was published by C. H. Bennett, G. Brassard, C. Crépeau, R. Jozsa, A. Peres and W. K. Wootters in 1993. Since then, quantum teleportation has been realized in various physical systems. Presently, the record distance for quantum teleportation is 143 km (89 mi) with photons, and 21 m with material systems. In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]

## Quantum Computing

A team of electrical engineers at UNSW Australia has observed the unique quantum behavior of a pair of spins in silicon and designed a new method to use them for "2-bit" quantum logic operations.

These milestones bring researchers a step closer to building a quantum computer, which promises dramatic data processing improvements.

Quantum bits, or qubits, are the building blocks of quantum computers. While many ways to create a qubits exist, the Australian team has focused on the use of single atoms of phosphorus, embedded inside a silicon chip similar to those used in normal computers.

The first author on the experimental work, PhD student Juan Pablo Dehollain, recalls the first time he realized what he was looking at.

"We clearly saw these two distinct quantum states, but they behaved very differently from what we were used to with a single atom. We had a real 'Eureka!' moment when we realized what was happening – we were seeing in real time the `entangled' quantum states of a pair of atoms." [5]

## Quantum Entanglement

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

## The Bridge

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

### Accelerating charges

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

### Relativistic effect

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

## Heisenberg Uncertainty Relation

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

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

## Wave – Particle Duality

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

## Atomic model

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

## The Relativistic Bridge

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

## The weak interaction

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

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

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

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

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

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

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

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

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

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

## The General Weak Interaction

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

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

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

There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.
The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

## Fermions and Bosons

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

## Van Der Waals force

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

## Electromagnetic inertia and mass

### Electromagnetic Induction

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

### Relativistic change of mass

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

### The frequency dependence of mass

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

### Electron – Proton mass rate

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

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

# Gravity from the point of view of quantum physics

## The Gravitational force

The gravitational attractive force is basically a magnetic force.

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

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

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

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

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

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.

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

## The Higgs boson

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

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

## Higgs mechanism and Quantum Gravity

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

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

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

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

### What is the Spin?

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

### The Graviton

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

## Conclusions

The method developed by the researchers involves transferring a photonic qubit to an atomic qubit trapped inside an optical cavity. The photon-atom quantum information transfer is initiated via a quantum “logic-gate” operation, performed by reflecting the photon from the atom-cavity system, which creates an entangled atom-photon state. [9]
In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]
One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .
The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]
The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing.
The Secret of Quantum Entanglement that the particles are diffraction patterns of the electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]
The key breakthrough to arrive at this new idea to build qubits was to exploit the ability to control the nuclear spin of each atom. With that insight, the team has now conceived a unique way to use the nuclei as facilitators for the quantum logic operation between the electrons. [5]
Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions also.

## References

[1] The Magnetic field of the Electric current and the Magnetic induction

http://academia.edu/3833335/The_Magnetic_field_of_the_Electric_current

[2] 3 Dimensional String Theory

http://academia.edu/3834454/3_Dimensional_String_Theory

[3] Graviton Production By Two Photon and Electron-Photon Processes In Kaluza-Klein Theories With Large Extra Dimensions

http://arxiv.org/abs/hep-ph/9909392

[4] Quantum Entanglement

http://en.wikipedia.org/wiki/Quantum_entanglement

[5] Pairing up single atoms in silicon for quantum computing

http://phys.org/news/2014-06-pairing-atoms-silicon-quantum.html#nwlt

[6] How to Win at Bridge Using Quantum Physics

http://www.wired.com/2014/06/bridge-quantum-mechanics/

[7] Information Entropy-Theory of Physics

https://www.academia.edu/3836084/Information_-_Entropy_Theory_of_Physics

[8] Quantum Teleportation

http://en.wikipedia.org/wiki/Quantum_teleportation

[9] Synopsis: Heralded Qubit Transfer

http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.114.220501

[10] Semiconductor quantum dots as ideal single-photon source

http://www.nanowerk.com/nanotechnology-news/newsid=41243.php

[11] Single-photon source is efficient and indistinguishable

http://physicsworld.com/cws/article/news/2016/jan/29/single-photon-source-is-efficient-and-indistinguishable

[12] Superfast light source made from artificial atom

http://phys.org/news/2016-04-superfast-source-artificial-atom.html

[13] Team demonstrates large-scale technique to produce quantum dots

http://phys.org/news/2016-05-team-large-scale-technique-quantum-dots.html

[14] Quantum dot LEDs that can produce entangled photons

http://phys.org/news/2016-11-quantum-dot-entangled-photons.html

[15] Superlattice of single-atom magnets aims for ultimate limit of high-density data storage

http://phys.org/news/2016-11-superlattice-single-atom-magnets-aims-ultimate.html

[16] A new perovskite could lead the next generation of data storage

http://phys.org/news/2016-11-perovskite-storage.html

[17] New ultra-high density optical storage technology

http://phys.org/news/2016-12-ultra-high-density-optical-storage-technology.html

[18] Investigations of the skyrmion Hall effect reveal surprising results

http://phys.org/news/2016-12-skyrmion-hall-effect-reveal-results.html

[19] Liquid light switch could enable more powerful electronics

http://www.cam.ac.uk/research/news/liquid-light-switch-could-enable-more-powerful-electronics

[20] Random access memory on a low energy diet: Researchers develop basis for a novel memory chip

http://phys.org/news/2017-01-random-access-memory-energy-diet.html

[21] Engineers work on promising new memory technology

https://phys.org/news/2017-01-memory-technology.html

[22] Magnetic recording with light and no heat on garnet

https://phys.org/news/2017-01-magnetic-garnet.html

[23] Now Quantum Computers Can Send Information Using a Single Particle of Light

http://www.trendintech.com/2017/01/15/now-quantum-computers-can-send-information-using-a-single-particle-of-light/

[24] Physicists show that real-time error correction in quantum communications is possible

**https://phys.org/news/2017-01-physicists-real-time-error-quantum.html**

[25] Synopsis: Quantum Signals Outpace Classical Ones

http://physics.aps.org/synopsis-for/10.1103/PhysRevA.95.012331