Helical Quantum Hall Phase in Graphene

In a new report now on Science, Louis Veyrat and a research team in materials science, quantum optics and optoelectronics in France, China and Japan tuned the ground state of the graphene zeroth Landau level i.e. orbitals occupied by charged particles with discrete energy values. [23]

Combining our nano-SQUID on tip with scanning gate measurements in the quantum Hall phase of graphene we were able to measure and identify work and heat dissipation processes separately. [22]

Probing the properties of a Mott insulator, a team of researchers from Boston College, MIT, and U.C. Santa Barbara has revealed an elusive atomic-scale magnetic signal in the unique material as it transitions from insulator to a metal, the team reported recently in the journal Nature Physics. [21]

UC Santa Barbara engineer Galan Moody, an assistant professor of electrical and computer engineering, has proposed a solution to overcome the poor efficiency and performance of existing quantum computing prototypes that use light to encode and process information. [20]

JILA physicists and collaborators have demonstrated the first next-generation "time scale"—a system that incorporates data from multiple atomic clocks to produce a single highly accurate timekeeping signal for distribution. [19]

Researchers have succeeded in creating an efficient quantum-mechanical light-matter interface using a microscopic cavity. [18]

Our researchers were the first to produce these knots as part of a collaboration between Aalto University and Amherst College, U.S., and they have now studied how the knots behave over time. [17]

The groundbreaking result sheds light on an elusive phenomenon whose existence, a natural outcome of the hundred-year-old theory of superconductivity, has long been speculated, but never actually observed. [16]

Now a team of researchers from the University of Maryland (UMD) Department of Physics together with collaborators has seen exotic superconductivity that relies on highly unusual electron interactions. [15]

A group of researchers from institutions in Korea and the United States has determined how to employ a type of electron microscopy to cause regions within an iron-based superconductor to flip between superconducting and non-superconducting states. [14]

In new research, scientists at the University of Minnesota used a first-of-its-kind device to demonstrate a way to control the direction of the photocurrent without deploying an electric voltage. [13]

Brown University researchers have demonstrated for the first time a method of substantially changing the spatial coherence of light. [12]

Researchers at the University of Central Florida have generated what is being deemed the fastest light pulse ever developed. [11]

Physicists at Chalmers University of Technology and Free University of Brussels have now found a method to significantly enhance optical force. [10]

Nature Communications today published research by a team comprising Scottish and South African researchers, demonstrating entanglement swapping and teleportation of orbital angular momentum 'patterns' of light. [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

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]

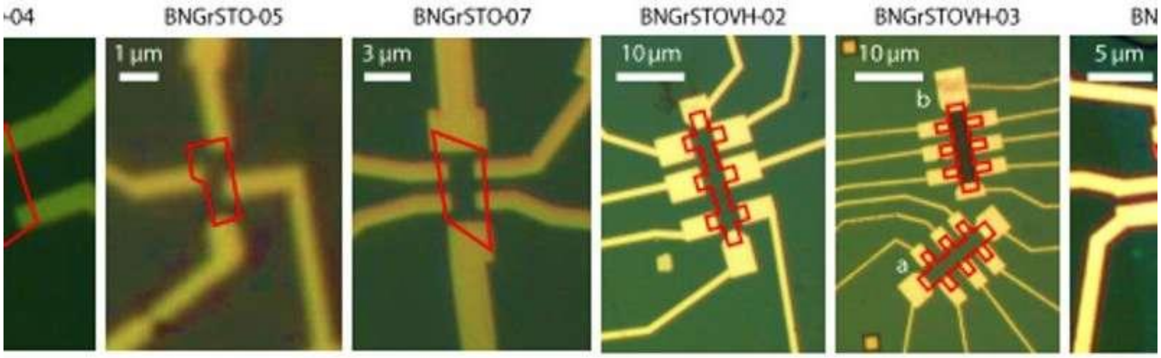
I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

Helical quantum Hall phase in graphene on strontium titanate

Materials that exhibit topological phases can be classified by their dimensionality, symmetries and topological invariants to form conductive-edge states with peculiar transport and spin properties. For example, the quantum Hall effect can arise in two-dimensional (2-D) electron systems subjected to a perpendicular magnetic field. When distinct characteristics of quantum Hall systems are compared with time-reversal symmetric (entropy conserved) topological insulators (TIs), they appear to rely on Coulomb interactions between electrons to induce a wealth of strongly correlated, topologically or symmetry-projected phases in a variety of experimental systems.

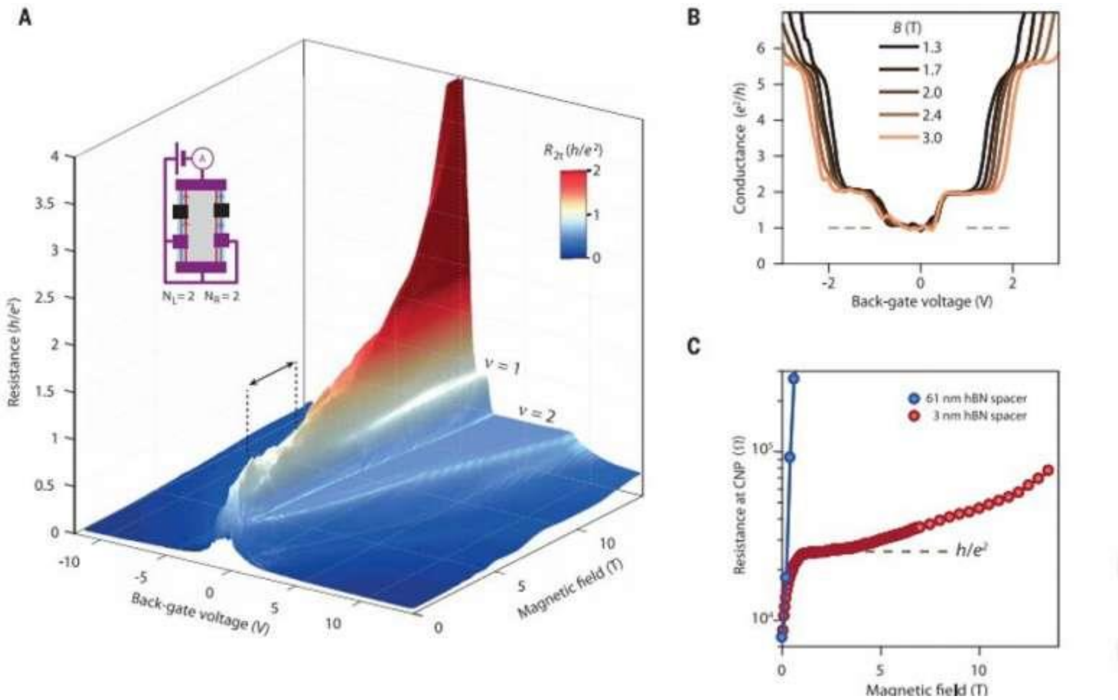
In a new report now on *Science*, Louis Veyrat and a research team in materials science, quantum optics and optoelectronics in France, China and Japan tuned the ground state of the graphene zeroth Landau level i.e. orbitals occupied by charged particles with discrete energy values. Using suitable screening of the Coulomb interaction with the high dielectric constant of a strontium titanate ($SrTiO_3$) substrate, they observed robust helical edge transport at magnetic fields as low as 1 Tesla, withstanding temperatures of up to 110 kelvin across micron-long distances. These versatile graphene platforms will have applications in spintronics and topological quantum computation.

Topological insulators (TIs), i.e., a material that behaves as an insulator in its interior but retains a conducting surface state, with zero Chern number have emerged as quantum Hall topological insulators (QHTIs) arising from many-body interacting Landau levels. They can be pictured as two independent copies of quantum Hall systems with opposite chirality, but the experimental system is at odds with the described scenario, where a strong insulating state is observed on increasing the perpendicular magnetic field in charge-neutral, high-mobility graphene devices.



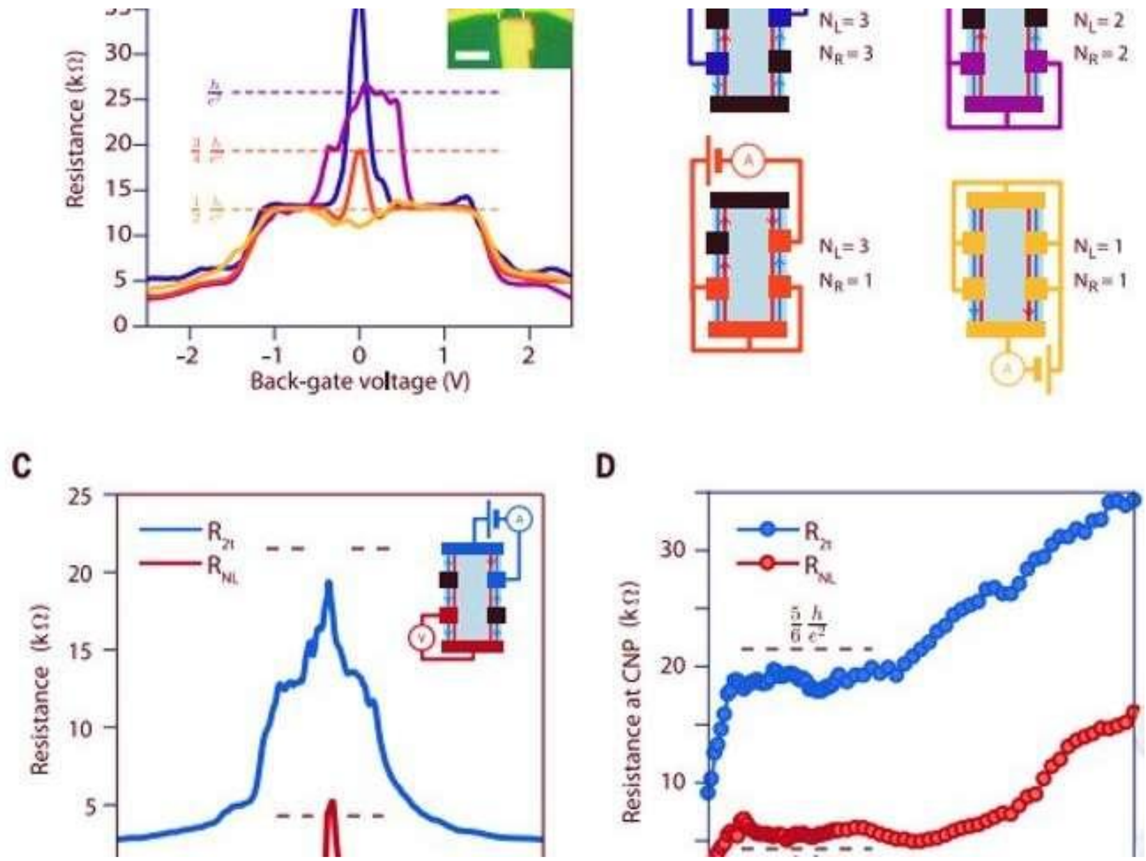
Graphene devices. Optical pictures of diverse samples. The red lines underline the edges of the hBN-encapsulated graphene flakes. Credit: Science, doi: 10.1126/science.aax8201

The experimental formation of the ferromagnetic (F) phase (F-phase) in graphene is therefore potentially hindered by such lattice-scale electron-electron and electron-phonon interactions. To overcome this, scientists had previously applied a very strong in-plane magnetic field component higher than 30 Tesla to surpass anisotropic interactions, allowing the F-phase to experimentally emerge in graphene. In another strategy they used graphene bilayers hosting two different quantum Hall states of opposite charge-carrier types, but they suffered from an impractically strong and tilted magnetic field or complexity of materials assembly. As a result, in this work Veyrat et al. used a different approach to induce the F-phase in monolayer graphene. Instead of boosting the Zeeman energy or Zeeman effect i.e. splitting a spectral line using a magnetic field to overcome anisotropic interactions, they modified the lattice-scale interactions relative to Coulomb interactions to restore the dominant role of the spin-polarizing terms and induce the F-phase.



Low–magnetic field quantum spin Hall effect. (A) Two-terminal resistance R2t in units of h/e2 of sample BNGrSTO-07 versus magnetic field and back-gate voltage measured at 4 K. In addition to standard quantum Hall plateaus at filling fractions n = 1 and 2, the resistance exhibits an anomalous plateau around the charge neutrality point between B = 1.5 and 4 T, delimited by the black dashed lines and the double-headed arrow, which signals the regime of the QSH effect in this sample. The value of the resistance at this plateau is h/e2 and is color coded white. The inset schematic indicates the contact configuration. Black contacts are floating. The red and blue arrows on the helical edge channels indicate the direction of the current between contacts, and A indicates the ampere meter. (B) Two-terminal conductance G2t = 1/R2t in units of e2 /h versus back-gate voltage extracted from (A) at different magnetic fields. The first conductance plateaus of the quantum Hall effect at 2e2 /h and 6e2 /h are well defined. The QSH plateau of conductance e2 /h clearly emerges at charge neutrality around Vbg = 0 V. (C) Resistance at the charge neutrality point (CNP) versus magnetic field for sample BNGrSTO-07 (red dots) extracted from (A) and sample BNGrSTO-09 (blue dots). The latter sample has a thick hBN spacer and exhibits a strong positive magnetoresistance at low magnetic field diverging toward insulation; the sample with the thin hBN spacer (BNGrSTO-07) shows a QSH plateau that persists up to ~4 T, followed by a resistance increase at higher magnetic field. W, ohms. Credit: Science, doi: 10.1126/science.aax8201

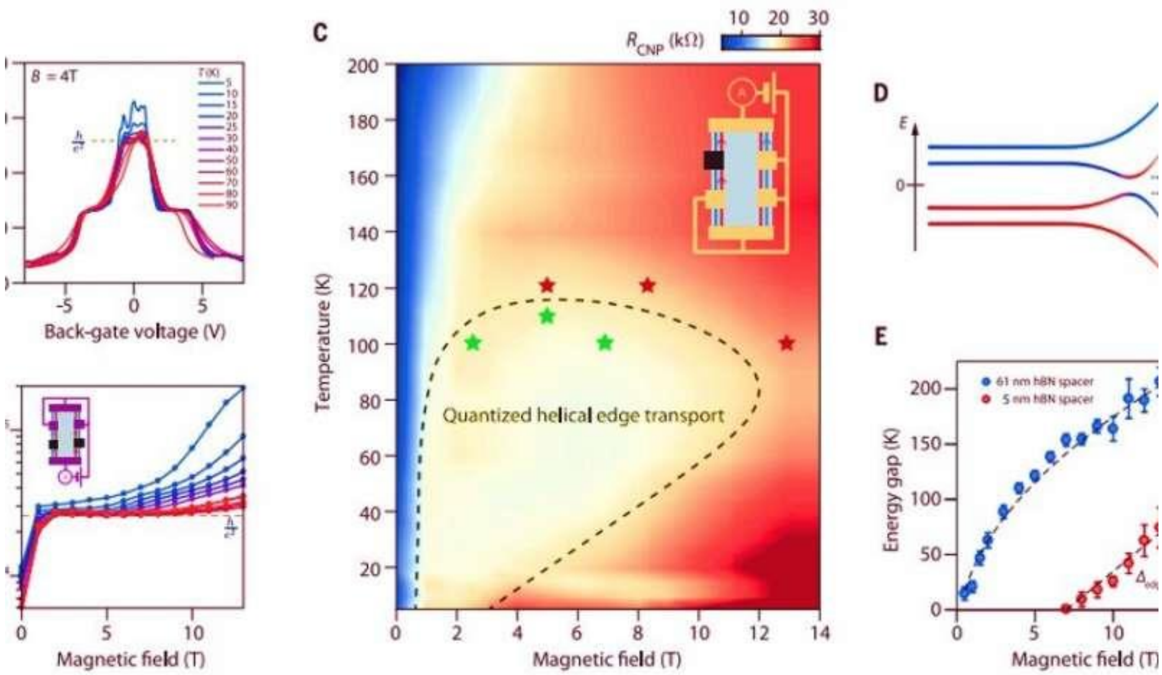
For this, they used quantum paraelectric strontium titanate ($SrTiO_3$), known to exhibit a large static dielectric constant (D≈10^4) at low temperatures. The setup eventually modified the ground state of graphene at charge neutrality. Veyrat et al. accomplished this by engineering high-mobility graphene heterostructures based on hexagonal boron nitride (hBN) encapsulation and readily observed the emergence of the F-phase in a screened configuration. By changing the source of electrons and drain (flow of electrons) contacts in the setup, and the number of helical edge sections, they observed helical edge transport. Veyrat et al. also observed simultaneous measurements of two-terminal resistances and non-local resistance while keeping the same source and drain current-injection contacts to demonstrate current flow on the edges of the sample.



Nonlocal helical edge transport. (A) Two-terminal resistance versus back-gate voltage measured at 2.5 T and 4 K for different contact configurations schematized in (B). The inset shows an optical picture of the measured sample BNGrSTO-07. The scale bar is 4 mm. Each contact configuration yields a resistance at charge neutrality reaching the expected values for helical edge transport, which are indicated with the horizontal dashed lines. (B) Schematics of the measurement configurations. Black contacts are floating. The red and blue arrows on the helical edge channels indicate the direction of the current between contacts. (C) Two-terminal resistance, R2t, in blue and nonlocal, four-terminal resistance, RNL, in red versus back-gate voltage in the contact configuration shown in the inset schematic. In the schematic, V indicates the voltmeter. (D) Resistance at the CNP, Vbg = 0 V, in the same contact configuration as in (C) versus magnetic field. The helical plateau is observed for both two- and four-terminal resistances between 1 T and about 6 T. Credit: Science, doi: 10.1126/science.aax8201

To investigate robustness of helical edge transport, the team conducted systematic studies of its temperature and magnetic field dependence. The $SrTiO_3$ dielectric constant remained high enough up to 200 K, and the dielectric screening remained virtually unaffected. To understand the limit of quantized helical edge transport, the team measured different contact configurations at several magnetic field and temperature values to show that quantized helical edge transport could withstand very high temperatures of up to 110 K.

The team then demonstrated the key role of the $SrTiO_3$ dielectric substrate during F-phase establishment. Due to substantially reduced electron-electron interactions in a high-dielectric constant measurement, the F-phase emerged as a ground state in the control experiments. Veyrat et al. further investigated the screening effects and short-range lattice-scale contributions of the Coulomb and electron-phonon interactions to determine the energetically favorable ground state. The observed mechanisms will open exciting new perspectives. For instance, the Coulomb energy scale could be enhanced by increasing the magnetic field to induce a topological quantum phase transition from the QHTI (quantum Hall topological insulators) ferromagnetic phase to an insulating, trivial quantum Hall ground state—a type of transition hitherto little addressed.



Phase diagram of the helical edge transport. (A) Two-terminal resistance of sample BNGrSTO-07 versus back-gate voltage measured at various temperatures and a magnetic field of 4 T. The back-gate voltage is renormalized to compensate the temperature-dependence of the substrate dielectric constant. (B) Two-terminal resistance at the CNP for the same data as in (A). The inset shows the contact configuration used in (A) and (B). (C) Two-terminal resistance at the CNP versus magnetic field and temperature for a different contact configuration shown in the inset. The resistance shows a plateau at the value expected for helical edge transport (2 3 h e2 , color coded light yellow) over a large range of temperatures and magnetic fields, that is, up to T = 110 K at B = 5 T. The stars indicate the parameters at which helical edge transport has been checked by measuring different contact configurations. (Green stars indicate quantized helical edge transport, and red stars indicate deviation to quantization at the CNP.) The dashed curve is a guide for the eye showing the approximate limits of the quantized helical edge transport of the F phase. (D) Schematic of the edge dispersion of the zeroth Landau level broken-symmetry states showing the opening of a gap at the edge. (E) Activation energy at the charge neutrality point versus magnetic field measured in samples BNGrSTOVH-02 (red dots) and BNGrSTO-09 (blue dots), which have hBN spacers of 5 and 61 nm, respectively. The dashed lines are a linear fit for BNGrSTOVH-02 and a fit of the dependence for BNGrSTO-09. The prefactor α = 64 KT−1/2 corresponds to a disorder-free gap, and the intercept describes the disorder-broadening of the Landau levels, which is consistent with the sample mobility. Credit: Science, doi: 10.1126/science.aax8201

In this way, Louis Veyrat and colleagues demonstrated the ferromagnetic (F) phase in screened graphene. The setup emerged at low magnetic fields as a prototypical interaction-induced topological phase with robust helical edge transport. The edge excitations were tunable with magnetic fields to study zero-energy modes in superconductivity-proximitized architectures. The method of substrate-screening engineering was tunable due to the thickness of the hBN spacer used in the study, the team therefore expect the ground states and optoelectronic properties of other correlated 2-D systems to be as strongly influenced by their dielectric environment. [23]

Probing work and heat dissipation in the quantum Hall edges of graphene

Combining our nano-SQUID on tip with scanning gate measurements in the quantum Hall phase of graphene we were able to measure and identify work and heat dissipation processes separately. The measurements show that the dissipation is governed by crosstalk between counterpropagating pairs of downstream and upstream channels that appear at graphene boundaries because of edge reconstruction.

Instead of local Joule heating, however, the dissipation mechanism comprises two distinct and spatially separated processes. The work generating process that we image directly and which involves elastic tunneling of charge carriers between the quantum channels, determines the transport properties but does not generate local heat.

The independently visualized heat and entropy generation process, in contrast, occurs nonlocally upon inelastic resonant scattering off single atomic defects at graphene edges (see also our previous work) , while not affecting the transport. Our findings offer a crucial insight into the mechanisms concealing the true topological protection and suggest venues for engineering more robust quantum states for device applications. Below are sequences of scans measured on different graphene devices at 4.2 K.

A sequence of scanning gate images of the four-probe resistance Rxx (r) in a zoomed-in region along the top boundary of the same sample as in Video 1. The Rxx (r)=Vxx (r)/Idc is recorded as a function of the tip position r for various back gate voltages Vbg. Here the injected total power is smaller compared to Video 1. The dashed horizontal line denotes the top edge of the sample.

Video V3 shows an example of the evolution of the simultaneously acquired thermal and scanning gate Rxx (r) images upon varying Vpg. For this high Vtg (6 V) the "entropy rings" and the " work arc-like features" are readily resolved. The rings due to phonon emission at the atomic defects are observed in the thermal images along the entire graphene perimeter, visible in the form of smaller diameter sharp rings. They are powered by the remote work process even when the latter are shifted significantly away from the edges by the plunger gate potential. These rings are invisible in the Rxx (r) images since the dissipation processes do not cause carrier back scattering. The larger "work" arc-like features are clearly visualized in the Rxx (r) images (light blue to red) revealing the work generation through carrier backscattering. Since the work causes nonlocal heating, these features are also observed in the thermal images in a form of halos along their outer contours.

Remarkably, the tip induced resistance can be extremely large, Rxx (r)≫R0, with Rxx (r)-R0 reaching several kΩ and up to 20 kΩ in the zeroth Landau level. Despite its very large value we find that Rxx (r) is essentially current independent as demonstrated in Video V4. Here the ac current Iac is varied by over more than two orders of magnitude from 10 nA to 1.4 μA with only minor change in Rxx (r). The current independent Rxx (r) implies that the resulting work and the nonlocal heat dissipation increase quadratically with Iac. Indeed, the second harmonic thermal signal in Video V4 is below our sensitivity at low currents and grows quadratically with the current. Note that the sharp thermal rings in the images at elevated currents are district from the "work" arc-like patterns visible both in thermal and Rxx (r) scans.

Video V5 shows an example of the evolution of Rxx (r) upon varying V_tg at a neutral plunger gate, and very low current of Iac= 10 nA. A negative Vtg causes accumulation of holes under the tip, but this has no observable effect. This is because hole accumulation is already present along the edges and increasing this accumulation in a very small region does not influence (decrease) the backscattering appreciably. As Vtg is increased to small positive values, the induced depletion of the hole accumulation causes compression of the counterpropagating channels resulting in enhanced backscattering and appearance of corresponding features in R_xx (r) which reveal the locations of the most dominant scattering sites. When Vtg becomes sufficiently large (e.g. 1.75 V) to cut off the counterpropagating pairs of channels, the enhanced Rxx (r) becomes visible along the entire edge of the sample where the nontopological channels are present, displaying a highly disordered structure. For Vtg≳ 3 V arc-like features are formed which increase in diameter and become very fine upon further increase of Vtg. In this case an n-doped pocket is formed under the tip. At high Vtg this pocket will contain a number of Landau levels with edge channels strongly compressed against the steep edge potential, apparently causing enhanced backscattering between the channels by the resonant states at the individual atomic defects. The arcs are very fine at the applied low current of 10 nA and become more blurred at higher currents. [22]

Researchers reveal an elusive atomic-scale magnetic 'signal' in a Mott insulator

Probing the properties of a Mott insulator, a team of researchers from Boston College, MIT, and U.C. Santa Barbara has revealed an elusive atomic-scale magnetic signal in the unique material as it transitions from insulator to a metal, the team reported recently in the journal *Nature Physics*.

Working with a compound in the class of materials known as Mott insulators, the team used spin-polarizing scanning tunneling microscopy (SP-STM) to detail at the atomic level the underlying physics of one example of these insulators, which can be manipulated into a metallic state through the addition of an electronic charge, a process called doping, said Boston College Assistant Professor of Physics Ilija Zeljkovic, a lead author of the report.

A Mott insulator is characterized by localization of electrons due to strong electron-electron interactions, and it is typically accompanied by magnetic ordering, Zelkjovic explained. In this case, the team developed and studied the surface of Mott insulator strontium iridate, an oxide, in the form of single crystals.

In many complex oxides, magnetic ordering is embedded within a spatially inhomogeneous landscape of other phases, he said. The team sought to perform measurements at single atom-length scales, with both charge and spin sensitivity in order to fully understand the underlying physics, a procedure that had yet to be achieved in any complex oxide.

By employing spin-polarizing scanning tunneling microscopy (SP-STM), Zeljkovic and his colleagues report that the team was able to perform this experiment for the first time. The measurements help to understanding how an antiferromagnetic Mott insulator evolves with charge carrier doping, which has puzzled scientists since the discovery of prototypical doped Mott insulators, which are copper-oxide high-temperature superconductors, Zeljkovic said.

By tracking its evolution with charge carrier doping, the researchers discovered that, with a low level of doping, the homogeneous antiferromagnetic order of the material's electrons melts into a fragmented, "patchy" antiferromagnetic order near the insulator-to-metal transition, the team reported.

Zeljkovic said the results advance the understanding of the unique characteristics of Mott insulators, and also establish SP-STM as a powerful tool capable of revealing atomic-scale information in complex oxides. [21]

Pushing quantum photonics

Quantum computers use the fundamentals of quantum mechanics to potentially speed up the process of solving complex computations. Suppose you need to perform the task of searching for a specific number in a phone book. A classical computer will search each line of the phone book until it finds a match. A quantum computer could search the entire phone book at the same time by assessing each line simultaneously and return a result much faster.

The difference in speed is due to the computer's basic unit for processing information. In a classical computer, that basic unit is called a bit, an electrical or optical pulse that represents either 0 or 1. A quantum computer's basic unit is a qubit, which can represent numerous combinations of values from 0 and 1 at the same time. It is this characteristic that may allow quantum computers to speed up calculations. The downside of qubits is that they exist in a fragile quantum state that is vulnerable to environmental noise, such as changes in temperature. As a result, generating and managing qubits in a controlled environment poses significant challenges for researchers.

UC Santa Barbara engineer Galan Moody, an assistant professor of electrical and computer engineering, has proposed a solution to overcome the poor efficiency and performance of existing quantum computing prototypes that use light to encode and process information. Optical systems are attractive because they naturally link quantum computing and networking in the same physical framework. However, existing technology still requires off-chip optical operations, which dramatically reduce efficiency, performance and scalability. In his project, "Heterogeneous III-V/Silicon Photonics for All-on-Chip: Linear Optical Quantum Computing," Moody aims to create an optical quantum computing platform in which all of the essential components are integrated onto a single semiconductor chip.

"Integrated electronic circuits enabled revolutionary advancements in classical computing. Our goal is to create integrated photonic circuits that have the same impact on quantum computing," said Moody, who joined UCSB's College of Engineering this fall after spending six years at the National Institute of Standards and Technology as a postdoctoral fellow and research scientist. "This could lead to a dramatic improvement in efficiency and processing speed and enable entirely new methods of processing and transmitting information using light."

Moody's research project has now received a significant boost from the United States Air Force. He is one of 40 early-career scientists selected for a 2019 Young Investigator Award from the Air Force Office of Scientific Research. Winners receive $450,000 over three years to support their work. The program is intended to foster research by young scientists that supports the Air Force's mission to control and maximize utilization of air, space and cyberspace, as well as related challenges in science and engineering.

"It's an honor to be among this group of talented awardees, and I am grateful for being selected," said Moody. "This award will allow my research group to make a more meaningful impact on the exciting and rapidly evolving quantum-information landscape."

In order to develop an all-electrical, all-on-chip quantum photonic platform, Moody proposes to integrate three technologies that have been developed for different platforms and applications. The components are electrically driven quantum dot single-photon sources, silicon-based photonics for optical operations, and superconducting nanowire single-photon detectors.

"We'll use physical modeling to guide the design and fabrication of the device," he said. "Quantum optical spectroscopy will give us insight into material properties and noise sources, and on-chip optical interferometers will enable measurements allowing us to improve material purity, monitor the light source and perform computations. Ultimately, we want to better understand and leverage any advantages that quantum mechanics can provide for computing and networking."

According to Moody, the new technology could also have transformative impacts in areas like turn-key quantum light sources for secure communications, and for reducing the size, weight and power consumption of classical photonic devices such as lasers and LEDs. [20]

JILA team demonstrates model system for distribution of more accurate time signals

JILA physicists and collaborators have demonstrated the first next-generation "time scale"—a system that incorporates data from multiple atomic clocks to produce a single highly accurate timekeeping signal for distribution. The JILA time scale outperforms the best existing hubs for disseminating official time worldwide and offers the possibility of providing more accurate time to millions of customers such as financial markets and computer and phone networks.

The novel time scale architecture combines a super-reliable, advanced atomic clock with an ultrastable device for storing time signals and is a "blueprint for the upgrade of time scales worldwide," as described in the journal *Physical Review Letters*.

JILA is jointly operated by the National Institute of Standards and Technology (NIST) and the University of Colorado Boulder.

"I think this new time scale demonstration will be very important for the redefinition of time in the future," said Jun Ye, NIST/JILA fellow and project leader.

The recent redefinition of the International System of Units (SI) did not update the way time is measured. The standard unit of time, the second, has been based on properties of the cesium atom since 1967. In the coming years, the international scientific community is expected to redefine the second, selecting a new atom as the basis for standard atomic clocks and official timekeeping.

To prepare for this change, researchers need to upgrade systems for distributing time.

NIST operates the nation's civilian time scales, arrays of hydrogen masers—microwave versions of lasers—that provide reliable oscillating signals to maintain stable "ticking" for the official U.S. civilian time of day, which is linked to international time (coordinated universal time or UTC). Two atomic clocks based on the cesium standard, called NIST-F1 and NIST-F2, are used to calibrate and ensure the accuracy of the time scales.

Like next-generation atomic clocks, JILA's experimental time scale operates entirely at optical frequencies, which are much higher than the microwave frequencies of cesium time standards. Optical frequencies divide time into smaller units and thus can offer greater accuracy.

Efforts to incorporate the latest optical atomic clocks into older microwave time scales have run into limits on long-term stability, due to the inherent properties of masers and the fluctuations associated with linking them to experimental clocks that operate intermittently.

The JILA team solved these problems by optimizing a more stable type of oscillator and tightly controlling operating conditions such as temperature so their highly stable and precise strontium lattice clock can be operated regularly on demand.

The oscillator is formed by a laser beam aimed into a hollow cavity made of a single crystal of silicon, inside of which laser light of a specific color, or frequency, bounces back and forth regularly for a long time, like a metronome. These devices have been around for years, but a long-term JILA collaboration with Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute, came up with a new way of building them, greatly improving the stability of the light. Recently, the JILA team further boosted the long-term stability of their cavity, which is 21 centimeters long and operates at cryogenic temperatures of 124 K (minus 149.15 C), by using superpolished optics and improved heat control, among other tweaks.

In the JILA time scale, an optical frequency comb (a ruler for light) transfers the stable optical signal from this cavity to another, very stable laser that is shined on the clock's atoms and synchronizes the light's frequency with their ticking. Two additional lasers are stabilized to independent cavities. The multiple lasers and cavities provide redundancy in case anything malfunctions.

The stability of the oscillator was compared continuously to that of the NIST microwave time scale by a preexisting underground fiber-optic link between JILA, on the university's campus, and NIST, a mile or so away. Over a month of measurements, the frequency stability of the optical oscillator consistently surpassed that of the masers in the microwave time scale.

The experimental results show that the JILA time scale architecture outperforms microwave time scales, even when the masers are calibrated by next-generation atomic clocks. The team's analysis indicates that by running the JILA optical clock 50% of the time, the all-optical time scale could reach a stability level about 10 times better than the standard microwave time scale, or 1×10^{-17}, after a few months of averaging.

A further practical advantage is that the oscillator frequency can be predicted using conventional microwave analysis techniques, enabling the team to estimate a timing error of only 48 ± 94 picoseconds (trillionths of a second) after 34 days of operation.

Additional technical upgrades are planned, including automation that should allow the clock to be operated more than 50% of the time. Researchers also plan to incorporate the optical time scale signal into the NIST time scale using the underground fiber network. [19]

A cavity leads to a strong interaction between light and matter

Researchers have succeeded in creating an efficient quantum-mechanical light-matter interface using a microscopic cavity. Within this cavity, a single photon is emitted and absorbed up to 10 times by an artificial atom. This opens up new prospects for quantum technology, report physicists at the University of Basel and Ruhr-University Bochum in the journal *Nature*.

Quantum physics describes photons as light particles. Achieving an interaction between a single photon and a single atom is a huge challenge due to the tiny size of the atom. However, sending the photon past the atom several times by means of mirrors significantly increases the probability of an interaction.

In order to generate photons, the researchers use artificial atoms, known as quantum dots. These semiconductor structures consist of an accumulation of tens of thousands of atoms, but behave much like a single atom: when they are optically excited, their energy state changes and they emit a photon. "However, they have the technological advantage that they can be embedded in a semiconductor chip," says Dr. Daniel Najer, who conducted the experiment at the Department of Physics at the University of Basel.

System of quantum dot and microcavity

Normally, these light particles fly off in all directions like a light bulb. For their experiment, however, the researchers positioned the quantum dot in a cavity with reflective walls. The curved mirrors reflect the emitted photon back and forth up to 10,000 times, causing an interaction between light and matter.

Measurements show that a single photon is emitted and absorbed up to 10 times by the quantum dot. At the quantum level, the photon is transformed into a higher energy state of the artificial atom, at which point a new photon is created. And this happens very quickly, which is very desirable in terms of quantum technological applications: one cycle lasts just 200 picoseconds.

The conversion of an energy quantum from a quantum dot to a photon and back again is theoretically well supported, but "nobody has ever observed these oscillations so clearly before," says Professor Richard J. Warburton from the Department of Physics at the University of Basel.

Serial interaction of light and matter

The successful experiment is particularly significant because there are no direct photon-photon interactions in nature. However, a controlled interaction is required for use in quantum information processing.

By transforming light into matter according to the laws of quantum physics, an interaction between individual photons becomes indirectly possible—namely, via the detour of an entanglement between a photon and a single electron spin trapped in the quantum dot. If several such photons are involved, quantum gates can be created through entangled photons. This is a vital step in the generation of photonic qubits, which can store information by means of the quantum state of light particles and transmit them over long distances.

International collaboration

The experiment takes place in the optical frequency range and places high technical demands on the size of the cavity, which must be adapted to the wavelength, and the reflectivity of the mirrors, so that the photon remains in the cavity for as long as possible. [18]

Researchers watch quantum knots untie

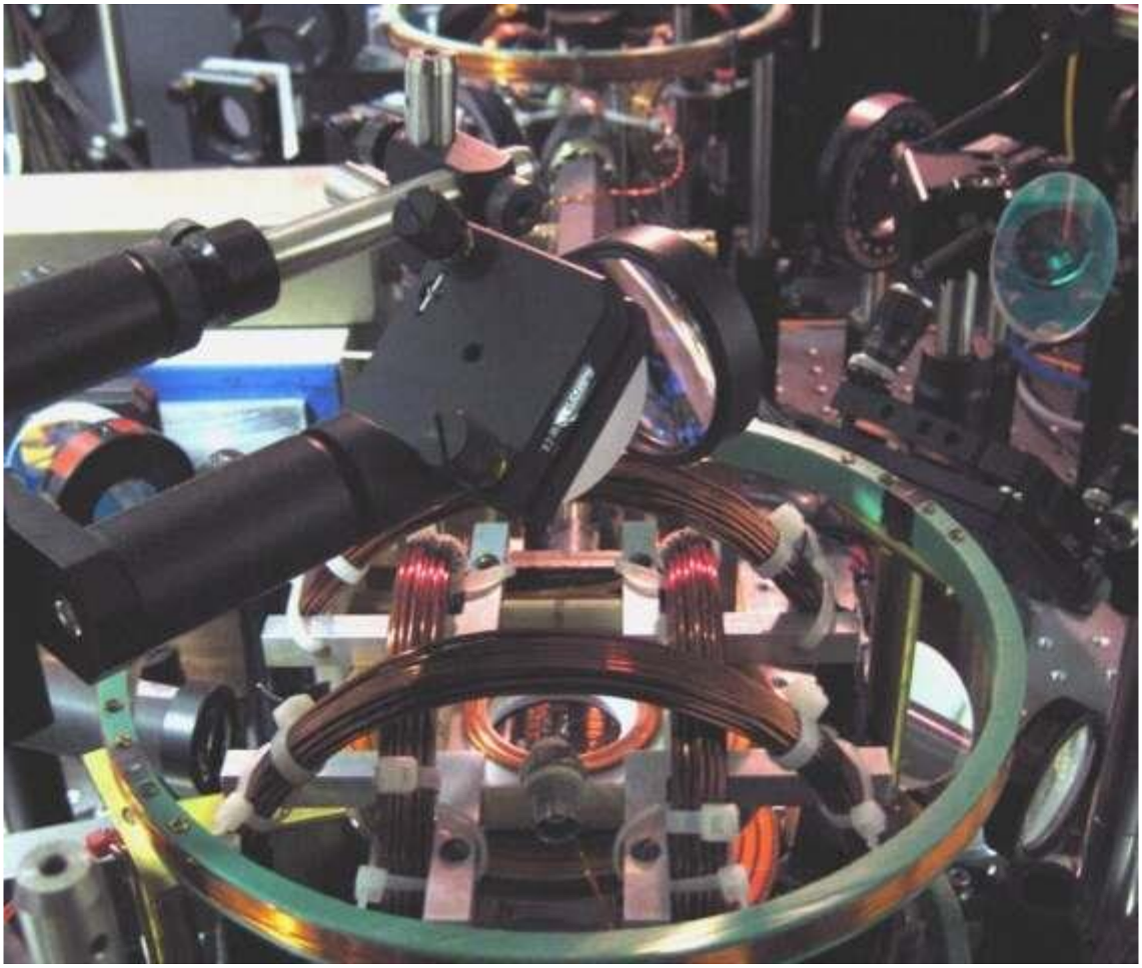
A quantum gas can be tied into knots using magnetic fields. Our researchers were the first to produce these knots as part of a collaboration between Aalto University and Amherst College, U.S., and they have now studied how the knots behave over time. The surprising result is that the knots untie themselves over a short period of time, before turning into a vortex.

The research was mainly carried out by Tuomas Ollikainen, a Ph.D. student at Aalto university who split his time between carrying out experimental work in Amherst in Massachusetts, and analyzing the data and developing his theories at Aalto.

"We hadn't been able to study the dynamics of these sorts of three-dimensional structures experimentally before, so this is the first step to this direction." says Ollikainen. "The fact that the knot decays is surprising, since topological structures like quantum knots are typically exceptionally stable. It's also exciting for the field because our observation that a three-dimensional quantum defect decays into a one-dimensional defect hasn't been seen before in these quantum gas systems'

Controlling quantum gases

The researchers hope their new study opens up new avenues in experimental research. One of the key breakthroughs in the study was being able to have better control over the state of the quantum gas, which allowed them to detect changes in its structure, like the decay of the knots and the formation of the vortex.



The experimental set-up at Amherst College where quantum gasses are made. Credit: David Hall/Amherst College

"Of course one can simulate these things but actually making quantum knots is not that easy. By being able to control the environment better we can explore different effects and get to understand more about these exciting quantum systems." tells Ollikainen.

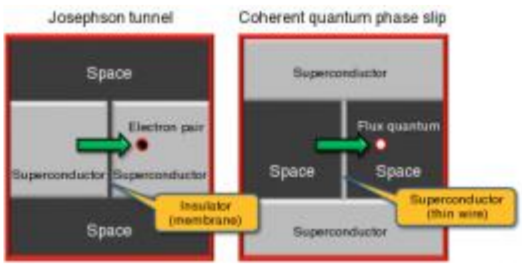
"When we tied quantum knots in 2016, it was the first realization of three-dimensionally winding topological structures. That was like breathing air another planet for the first time. Amazing." says Prof. Mikko Möttönen, head of Quantum Computing and Devices group where Ollikainen works.

"I know that many researchers have paid attention to our work and got inspiration to try this out in completely different type of systems. It would be great to see this technology being used some day in a practical application, which may well happen. Our latest results show that while quantum knots in atomic gases are exciting, you need to be quick to use them before they untie themselves. Thus the first applications are likely to be found in other systems," Möttönen says. [17]

Long predicted but never observed: A new kind of quantum junction

A new type of quantum bit called a "phase-slip qubit", devised by researchers at the RIKEN Advanced Science Institute and their collaborators, has enabled the world's first-ever experimental demonstration of coherent quantum phase slip (CQPS). The groundbreaking result sheds light on an elusive phenomenon whose existence, a natural outcome of the hundred-year-old theory of superconductivity, has long been speculated, but never actually observed.

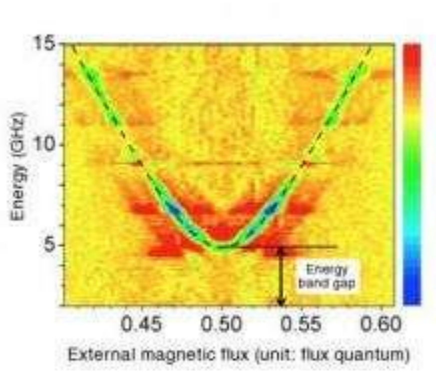
Superconductivity describes a phenomenon in which electrons pass through certain types of materials without any resistance when cooled below a given temperature. Among the most important applications of superconductivity is the Josephson junction, named after physicist Brian Josephson, who in 1962 predicted that a superconducting current could tunnel between superconductors separated by a thin insulating layer. This phenomenon, the Josephson effect, has been applied in a variety of areas including magnetometer design, voltage standardization, and quantum computing.



This figure shows the Josephson tunnel (left) and coherent quantum phase slip (right). At left, two superconductors are separated by thin insulator (in this case space). A current is produced by superconducting electron pairs tunneling ...more

Researchers have long known of an intriguing theoretical parallel to the Josephson effect in which insulator and superconductor are reversed: rather than electric charges jumping from one superconducting layer to another across an insulating layer, magnetic flux quanta jump from one insulator to another across a superconducting layer. Quantum tunneling of electrons in the Josephson junction is replaced in this parallel by the coherent "slip" of the phase, a quantum variable that, in superconducting circuits, plays a dual role to that of electric charge.

Coherent quantum phase slip (CQPS), as this phenomenon is known, has long been limited to theory—but no more. In a paper in *Nature*, Oleg Astafiev and colleagues at the RIKEN Advanced Science Institute (ASI) and NEC Smart Energy Research Laboratories report on the first direct observation of CQPS in a narrow superconducting wire of indium-oxide (InOx). The wire is inserted into a larger superconducting loop to form a new device called a phase-slip qubit, with the superconducting layer (the thin wire) sandwiched between insulating layers of empty space.



An energy band gap is obtained using energy spectroscopy. Existence of band gap establishes that coherent tunneling has occurred. Credit: RIKEN

By tuning the magnetic flux penetrating this loop while scanning microwave frequencies, the researchers detected a band gap in the energy curves for the two flux states of the system, just as theory predicts. This gap is a result of quantum mechanics, which prevents the two states from occupying the same energy level, forcing them to tunnel across the superconducting layer—and through a quantum phase-slip in the narrow wire—to avoid it. While demonstrating conclusively the existence of CQPS, the successful experiment also ushers in a novel class of devices that exploit the unique functionality of quantum phase-slip to forge a new path in superconducting electronics. [16]

A different spin on superconductivity—Unusual particle interactions open up new possibilities in exotic materials

Now a team of researchers from the University of Maryland (UMD) Department of Physics together with collaborators has seen exotic superconductivity that relies on highly unusual electron interactions. While predicted to occur in other non-material systems, this type of behavior has remained elusive. The team's research, published in the April 6 issue of *Science Advances*, reveals effects that are profoundly different from anything that has been seen before with superconductivity.

Electron interactions in superconductors are dictated by a quantum property called spin. In an ordinary superconductor, electrons, which carry a spin of ½, pair up and flow uninhibited with the help of vibrations in the atomic structure. This theory is well-tested and can describe the behavior of most superconductors. In this new research, the team uncovers evidence for a new type of superconductivity in the material YPtBi, one that seems to arise from spin-3/2 particles.

"No one had really thought that this was possible in solid materials," explains Johnpierre Paglione, a UMD physics professor and senior author on the study. "High-spin states in individual atoms are possible but once you put the atoms together in a solid, these states usually break apart and you end up with spin one-half. "

Finding that YPtBi was a superconductor surprised the researchers in the first place. Most superconductors start out as reasonably good conductors, with a lot of mobile electrons—an ingredient that YPtBi is lacking. According to the conventional theory, YPtBi would need about a thousand times more mobile electrons in order to become superconducting at temperatures below 0.8 Kelvin. And yet, upon cooling the material to this temperature, the team saw superconductivity happen anyway. This was a first sign that something exotic was going on inside this material.

After discovering the anomalous superconducting transition, researchers made measurements that gave them insight into the underlying electron pairing. They studied a telling feature of superconductors—their interaction with magnetic fields. As the material undergoes the transition to a superconductor, it will try to expel any added magnetic field from its interior. But the expulsion is not completely perfect. Near the surface, the magnetic field can still enter the material but then quickly decays away. How far it goes in depends on the nature of the electron pairing, and changes as the material is cooled down further and further.

To probe this effect, the researchers varied the temperature in a small sample of the material while exposing it to a magnetic field more than ten times weaker than the Earth's. A copper coil surrounding the sample detected changes to the superconductor's magnetic properties and allowed the team to sensitively measure tiny variations in how deep the magnetic field reached inside the superconductor.

The measurement revealed an unusual magnetic intrusion. As the material warmed from absolute zero, the field penetration depth for YPtBi increased linearly instead of exponentially as it would for a conventional superconductor. This effect, combined with other measurements and theory calculations, constrained the possible ways that electrons could pair up. The researchers concluded that the best explanation for the superconductivity was electrons disguised as particles with a higher spin—a possibility that hadn't even been considered before in the framework of conventional superconductivity.

The discovery of this high-spin superconductor has given a new direction for this research field. "We used to be confined to pairing with spin one-half particles," says Hyunsoo Kim, lead author and a UMD assistant research scientist. "But if we start considering higher spin, then the landscape of this superconducting research expands and just gets more interesting."

For now, many open questions remain, including how such pairing could occur in the first place. "When you have this high-spin pairing, what's the glue that holds these pairs together?" says Paglione. "There are some ideas of what might be happening, but fundamental questions remain-which makes it even more fascinating." [15]

Scientists control superconductivity using spin currents

A group of researchers from institutions in Korea and the United States has determined how to employ a type of electron microscopy to cause regions within an iron-based superconductor to flip between superconducting and non-superconducting states. This study, published in the December

1 edition of *Physical Review Letters*, is the first of its kind, and it opens a door to a new way of manipulating and learning about superconductors.

The iron-based superconductors, one of which was studied in this work, are one of several classes of these fascinating materials, which have the ability to conduct electricity with virtually zero resistance below a certain temperature. Scientists are still working out the complex atomic-level details that underlie these materials' electronic and magnetic behaviors. The iron-based materials, in particular, are known to display intriguing phenomena related to co-existing superconducting and magnetic states.

Here, researchers studied a compound composed of strontium (Sr), vanadium (V), oxygen (O), iron (Fe), and arsenic (As), with a structure consisting of alternating FeAs and Sr_2VO_3 layers. They probed its magnetic and electronic properties with a spin-polarized scanning tunneling microscope (SPSTM), a device that passes an atomically sharp metal tip – just a few atoms wide – over the surface of a sample. The tip and the sample do not touch but are brought in quantum-scale proximity to each other so that a bias voltage applied between them causes a current to flow between the tip and the sample. In this case, the current is spin-polarized, meaning its electrons tend to have the same spin – the tiny magnetic field carried by an electron that points either "up" or "down," like a bar magnet.

Typically, this material's FeAs layer is strongly superconducting and prefers a certain magnetic order, dubbed C_2 order, that refers to how the magnetic fields of its atoms (which are due, in turn, to electron spins) are arranged. Results of the SPSTM scan show that the injected spin-polarized current, when sufficiently high, induces a different magnetic order, C_4 order, in the FeAs layer. In that same local area, superconductivity somehow magically disappears.

"To our knowledge, our study is the first report of a direct real-space observation of this type of control by a local probe, as well as the first atomic-scale demonstration of the correlation between magnetism and superconductivity," said the paper's corresponding author, Jhinhwan Lee, a physicist at the Korea Advanced Institute of Science and Technology, to *Phys.org*.

Lee and his group introduced new ways to perform SPSTM using an antiferromagnetic chromium (Cr) tip. An antiferromagnet is a material in which the magnetic fields of its atoms are ordered in an alternating up-down pattern such that it has a minimal stray magnetic field that can inadvertently kill local superconductivity (which can happen with ferromagnetic tips, such as Fe tips, that other SPSTM researchers use). They compared these Cr tip scans with those taken with an unpolarized tungsten (W) tip. At low bias voltages, the surface scans were qualitatively identical. But as the voltage was increased using the Cr tip, the surface started to change, revealing the C_4 magnetic symmetry. The C_4 order held even when the voltage was lowered again, although was erased when thermally annealed (heat-treated) beyond a specific temperature above which any magnetic order in the FeAs layer disappears.

To study the connection between the C_4 magnetic order and the suppression of superconductivity, Lee and his group performed high-resolution SPSTM scans of the C_4 state with Cr tips and compared them with simulations. The results led them to suggest one possible explanation: that the low-energy spin fluctuations in the C_4 state cannot mediate pairing between electrons. This is critical because this pairing of electrons, defying their natural urge to repel each other, leads to superconductivity.

Spin-fluctuation-based pairing is one theory of electron pairing in iron-based superconductors; another set of theories assume that fluctuations in the electron orbitals are the key. Lee and his group believe that their results seem to support the former, at least in this superconductor.

"Our findings may be extended to future studies where magnetism and superconductivity are manipulated using spin-polarized and unpolarized currents, leading to novel antiferromagnetic memory devices and transistors controlling superconductivity," said Lee. [14]

Researchers steer the flow of electrical current with spinning light

Light can generate an electrical current in semiconductor materials. This is how solar cells generate electricity from sunlight and how smart phone cameras can take photographs. To collect the generated electrical current, called photocurrent, an electric voltage is needed to force the current to flow in only one direction.

In new research, scientists at the University of Minnesota used a first-of-its-kind device to demonstrate a way to control the direction of the photocurrent without deploying an electric voltage. The new study was recently published in the scientific journal *Nature Communications*.

The study reveals that control is effected by the direction in which the particles of light, called photons, are spinning—clockwise or counterclockwise. The photocurrent generated by the spinning light is also spin-polarized, which means there are more electrons with spin in one direction than in the other. This new device holds significant potential for use in the next generation of microelectronics using electron spin as the fundamental unit of information. It could also be used for energy efficient optical communication in data centers.

"The observed effect is very strong and robust in our devices, even at room temperature and in open air," said Mo Li, a University of Minnesota electrical and computer engineering associate professor and a lead author of the study. "Therefore, the device we demonstrate has great potential for being implemented in next-generation computation and communication systems."

Optical spin and topological insulators

Light is a form of electromagnetic wave. The way the electric field oscillates, either in a straight line or rotating, is called polarization. (Your polarized sunglasses block part of the unpleasant reflected light that is polarized along a straight line.) In circularly polarized light, the electric field can spin in the clockwise or counterclockwise direction. In such a state, the particle of light (photon) is said to have positive or negative optical spin angular momentum. This optical spin is analogous to the spin of electrons, and endows magnetic properties to materials.

Recently, a new category of materials, called topological insulators (TI), was discovered to have an intriguing property not found in common semiconductor materials. Imagine a road on which red cars only drive on the left lane, and blue cars only in the right lane. Similarly, on the surface of a TI, the electrons with their spins pointing one way always flow in one direction. This effect is called spin-momentum locking—the spin of the electrons is locked in the direction they travel.

Interestingly, shining a circularly polarized light on a TI can free electrons from its inside to flow on its surface in a selective way, for example, clockwise light for spin-up electrons and counterclockwise for spin-down electrons. Because of this effect, the generated photocurrent on the surface of the TI material spontaneously flows in one direction, requiring no electric voltage. This particular feature is significant for controlling the direction of a photocurrent. Because most of the electrons in this current have their spins pointing in a single direction, this current is spin-polarized.

Controlling direction and polarization

To fabricate their unique device that can change the direction of a photocurrent without the use of an electric voltage, the University's research team integrated a thin film of a TI material, bismuth selenide, on an optical waveguide made of silicon. Light flows through the waveguide (a tiny wire measuring 1.5 microns wide and 0.22 micron high) just like electrical current flows through a copper wire. Because light is tightly squeezed in the waveguide, it tends to be circularly polarized along a direction normal to the direction in which it flows. This is akin to the spin-momentum locking effect of the electrons in a TI material.

The scientists supposed that integrating a TI material with the optical waveguide will induce strong coupling between the light in the waveguide and the electrons in the TI material, both having the same, intriguing spin-momentum locking effect. The coupling will result in a unique optoelectronic effect—light flowing along one direction in the waveguide generates an electrical current flowing in the same direction with electron spin polarized.

Reversing the light direction reverses both the direction of the current and its spin polarization. And this is exactly what the team observed in their devices. Other possible causes of the observed effect, such as heat generated by the light, have been ruled out through careful experiments.

Future prospects

The outcome of the research is exciting for the researchers. It bears enormous potential for possible applications.

"Our devices generate a spin-polarized current flowing on the surface of a topological insulator. They can be used as a current source for spintronic devices, which use electron spin to transmit and process information with very low energy cost," said Li He, a University of Minnesota physics graduate student and an author of the paper.

"Our research bridges two important fields of nanotechnology: spintronics and nanophotonics. It is fully integrated with a silicon photonic circuit that can be manufactured on a large scale and has already been widely used in optical communication in data centers," He added. [13]

Research demonstrates method to alter coherence of light

Brown University researchers have demonstrated for the first time a method of substantially changing the spatial coherence of light.

In a paper published in the journal Science Advances, the researchers show that they can use surface plasmon polaritons—propagating electromagnetic waves confined at a metal-dielectric interface—to transform light from completely incoherent to almost fully coherent and vice versa. The ability to modulate coherence could be useful in a wide variety of applications from structural coloration and optical communication to beam shaping and microscopic imaging.

"There had been some theoretical work suggesting that coherence modulation was possible, and some experimental results showing small amounts of modulation," said Dongfang Li, a postdoctoral researcher in Brown's School of Engineering and the study's lead author. "But this is the first time very strong modulation of coherence has been realized experimentally."

Coherence deals with the extent to which propagating electromagnetic waves are correlated with each other. Lasers, for example, emit light that's highly coherent, meaning the waves are strongly correlated. The sun and incandescent light bulbs emit weakly correlated waves, which are generally said to be "incoherent", although, more precisely, they are characterized by low yet measurable degrees of coherence.

"Coherence, like color and polarization, is a fundamental property of light," said Domenico Pacifici, an associate professor of engineering and physics at Brown and coauthor of the research. "We have filters that can manipulate the color of light and we have things like polarizing sunglasses that can manipulate polarization. The goal with this work was to find a way to manipulate coherence like we can these other properties."

To do that, Li and Pacifici took a classic experiment used to measure coherence, Young's double slit, and turned it into a device that can modulate coherence of light by controlling and finely tuning the interactions between light and electrons in metal films.

In the classic double-slit experiment, an opaque barrier is placed between a light source and a detector. The light passes through two parallel slits in the barrier to reach the detector on the other side. If the light shown on the barrier is coherent, the rays emanating from the slits will interfere with each other, creating an interference pattern on the detector—a series of bright and dark bands called interference fringes. The extent to which the light is coherent can be measured by the intensity of bands. If the light is incoherent, no bands will be visible.

"As this is normally done, the double-slit experiment simply measures the coherence of light rather than changing it," Pacifici said. "But by introducing surface plasmon polaritons, Young's double slits become a tool not just for measurement but also modulation."

To do that, the researchers used a thin metal film as the barrier in the double slit experiment. When the light strikes the film, surface plasmon polaritons—ripples of electron density created when the electrons are excited by light—are generated at each slit and propagate toward the opposite slit.

"The surface plasmon polaritons open up a channel for the light at each slit to talk to each other," Li said. "By connecting the two, we're able to change the mutual correlations between them and therefore change the coherence of light."

In essence, surface plasmon polaritons are able to create correlation where there was none, or to cancel any existing correlation that was there, depending on the nature of the light coming in and the distance between the slits.

One of the study's key results is the strength of the modulation they achieved. The technique is able to modulate coherence across a range from 0 percent (totally incoherent) to 80 percent (nearly full coherent). Modulation of such strength has never been achieved before, the researchers say, and it was made possible by using nanofabrication methods that allowed to maximize the generation efficiencies of surface plasmon polaritons existing on both surfaces of the slitted screen.

This initial proof-of-concept work was done at the micrometer scale, but Pacifici and Li say there's no reason why this couldn't be scaled up for use in a variety of settings.

"We've broken a barrier in showing that it's possible to do this," Pacifici said. "This clears the way for new two-dimensional beam shapers, filters and lenses that can manipulate entire optical beams by using the coherence of light as a powerful tuning knob." [12]

53 attoseconds: Research produces shortest light pulse ever developed

Researchers at the University of Central Florida have generated what is being deemed the fastest light pulse ever developed.

The 53-attosecond pulse, obtained by Professor Zenhgu Chang, UCF trustee chair and professor in the Center for Research and Education in Optics and Lasers, College of Optics and Photonics, and Department of Physics, and his group at the university, was funded by the U.S. Army Research Laboratory's Army Research Office.

Specifically, it was funded by ARO's Multidisciplinary University Research Initiative titled "Post-BornOppenheimer Dynamics Using Isolated Attosecond Pulses," headed by ARO's Jim Parker and Rich Hammond.

This beats the team's record of a 67-attosecond extreme ultraviolet light pulse set in 2012.

Attosecond light pulses allow scientists to capture images of fast-moving electrons in atoms and molecules with unprecedented sharpness, enabling advancements in solar panel technology, logic and memory chips for mobile phones and computers, and in the military in terms of increasing the speed of electronics and sensors, as well as threat identification.

"This is the shortest laser pulse ever produced," Hammond said. "It opens new doors in spectroscopy, allowing the identification of pernicious substances and explosive residue."

Hammond noted that this achievement is also a new and very effective tool to understand the dynamics of atoms and molecules, allowing observations of how molecules form and how electrons in atoms and molecules behave.

"This can also be extended to condensed matter systems, allowing unprecedented accuracy and detail of atomic, molecular, and even phase, changes," Hammond said. "This sets the stage for many new kinds of experiments, and pushes physics forward with the ability to understand matter better than ever before."

Chang echoed Hammond's sentiments about this achievement being a game-changer for continued research in this field.

"The photon energy of the attosecond X-ray pulses is two times higher than previous attosecond light sources and reached the carbon K-edge (284 eV), which makes it possible to probe and control core electron dynamics such as Auger processes," Chang said. "In condensed matter physics, the ultrafast electronic process in carbon containing materials, such as graphene and diamond, can be studied via core to valence transitions. In chemistry, electron dynamics in carbon containing molecules, such as carbon dioxide, Acetylene, Methane, etc., may now be studied by attosecond transient absorption, taking advantage of the element specificity."

This development is the culmination of years of ARO funding of attosecond science.

It all started with an ARO MURI about eight years ago titled "Attosecond Optical Technology Based on Recollision and Gating" from the Physics Division. This was followed by single investigator awards, Defense University Research Instrumentation Programs and finally an ARO MURI titled "Attosecond Electron Dynamics" from the Chemistry Division.

From the ARL/ARO perspective, Hammond said that this achievement, which included researchers from around the globe, shows how continued funding into fundamental research using several instruments, such as MURIs, DURIPS, and single investigator awards, can be used in a coherent and meaningful way to push the forward the frontiers of science.

Chang's team includes Jie Li, Xiaoming Ren, Yanchun Yin, Andrew Chew, Yan Cheng, Eric Cunningham, Yang Wang, Shuyuan Hu, and Yi Wu, who are all affiliated with the Institute for the Frontier of Attosecond Science and Technology, or iFAST; Kun Zhao, who is also affiliated with the Chinese Academy of Sciences, and Michael Chini with the UCF Department of Physics. [11]

Method to significantly enhance optical force

Light consists of a flow of photons. If two waveguides – cables for light – are side by side, they attract or repel each other. The interaction is due to the optical force, but the effect is usually extremely small. Physicists at Chalmers University of Technology and Free University of Brussels have now found a method to significantly enhance optical force. The method opens new possibilities within sensor technology and nanoscience. The results were recently published in Physical Review Letters.

To make light behave in a completely new way, the scientists have studied waveguides made of an artificial material to trick the photons. The specially designed material makes all the photons move to one side of the waveguide. When the photons in a nearby waveguide do the same, a collection of photons suddenly gather very closely. This enhances the force between the waveguides up to 10 times.

"We have found a way to trick the photons so that they cluster together at the inner sides of the waveguides. Photons normally don't prefer left or right, but our metamaterial creates exactly that effect," says Philippe Tassin, Associate Professor at the Department of Physics at Chalmers University of Technology.

Philippe Tassin and Sophie Viaene at Chalmers and Lana Descheemaeker and Vincent Ginis at Free University of Brussels have developed a method to use the optical force in a completely new way. It can, for example, be used in sensors or to drive nanomotors. In the future, such motors might be used to sort cells or separate particles in medical technology.

"Our method opens up new opportunities for the use of waveguides in a range of technical applications. It is really exciting that man-made materials can change the basic characteristics of light propagation so dramatically," says Vincent Ginis, assistant professor at the Department of Physics at Free University of Brussels. [10]

Researchers demonstrate quantum teleportation of patterns of light

Nature Communications today published research by a team comprising Scottish and South African researchers, demonstrating entanglement swapping and teleportation of orbital angular momentum 'patterns' of light. This is a crucial step towards realizing a quantum repeater for high-dimensional entangled states.

Quantum communication over long distances is integral to information security and has been demonstrated in free space and fibre with two-dimensional states, recently over distances exceeding 1200 km between satellites. But using only two states reduces the information capacity of the photons, so the link is secure but slow. To make it secure and fast requires a higher-dimensional alphabet, for example, using patterns of light, of which there are an infinite number. One such pattern set is the orbital angular momentum (OAM) of light. Increased bit rates can be achieved by using OAM as the carrier of information. However, such photon states decay when transmitted over long distances, for example, due to mode coupling in fibre or turbulence in free space, thus requiring a way to amplify the signal. Unfortunately such "amplification" is not allowed in the quantum world, but it is possible to create an analogy, called a quantum repeater, akin to optical fibre repeaters in classical optical networks.

An integral part of a quantum repeater is the ability to entangle two photons that have never interacted - a process referred to as "entanglement swapping". This is accomplished by interfering two photons from independent entangled pairs, resulting in the remaining two photons becoming entangled. This allows the establishment of entanglement between two distant points without requiring one photon to travel the entire distance, thus reducing the effects of decay and loss. It also means that you don't have to have a line of sight between the two places.

An outcome of this is that the information of one photon can be transferred to the other, a process called teleportation. Like in the science fiction series, Star Trek, where people are "beamed" from one place to another, information is "teleported" from one place to another. If two photons are entangled and you change a value on one of them, then other one automatically changes too. This happens even though the two photons are never connected and, in fact, are in two completely different places.

In this latest work, the team performed the first experimental demonstration of entanglement swapping and teleportation for orbital angular momentum (OAM) states of light. They showed that quantum correlations could be established between previously independent photons, and that this could be used to send information across a virtual link. Importantly, the scheme is scalable to higher dimensions, paving the way for long-distance quantum communication with high information capacity.

Background

Present communication systems are very fast, but not fundamentally secure. To make them secure researchers use the laws of Nature for the encoding by exploiting the quirky properties of the quantum world. One such property is entanglement. When two particles are entangled they are connected in a spooky sense: a measurement on one immediately changes the state of the other no matter how far apart they are. Entanglement is one of the core resources needed to realise a quantum network.

Yet a secure quantum communication link over long distance is very challenging: Quantum links using patterns of light languish at short distances precisely because there is no way to protect the link against noise without detecting the photons, yet once they are detected their usefulness is destroyed. To overcome this one can have a repeating station at intermediate distances - this allows one to share information across a much longer distance without the need for the information to physically flow over that link. The core ingredient is to get independent photons to become entangled. While this has been demonstrated previously with two-dimensional states, in this work the team showed the first demonstration with OAM and in high-dimensional spaces. [9]

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]

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

In August 2013, the achievement of "fully deterministic" quantum teleportation, using a hybrid technique, was reported. On 29 May 2014, scientists announced a reliable way of transferring data by quantum teleportation. Quantum teleportation of data had been done before but with highly unreliable methods. [8]

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

The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]

The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. The Secret of Quantum Entanglement that the particles are diffraction patterns of the electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]

The key breakthrough to arrive at this new idea to build qubits was to exploit the ability to control the nuclear spin of each atom. With that insight, the team has now conceived a unique way to use the nuclei as facilitators for the quantum logic operation between the electrons. [5]

Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions also.

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