Quantum Magnetic Sensors

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In a recent experiment at EPFL, a microwave resonator, a circuit that supports electric signals oscillating at a resonance frequency, is coupled to the vibrations of a metallic micro-drum. [20]

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EPFL scientists have now carried out a study on a lithium-containing copper oxide and have found that its electrons are 2.5 times lighter than was predicted by theoretical calculations. [17]

Washington State University physicists have created a fluid with negative mass, which is exactly what it sounds like. Push it, and unlike every physical object in the world we know, it doesn't accelerate in the direction it was pushed. It accelerates backwards. [16]

When matter is cooled to near absolute zero, intriguing phenomena emerge. These include supersolidity, where crystalline structure and frictionless flow occur together. ETH researchers have succeeded in realising this strange state experimentally for the first time. [15]

Helium atoms are loners. Only if they are cooled down to an extremely low temperature do they form a very weakly bound molecule. In so doing, they can keep a tremendous distance from each other thanks to the quantum-mechanical tunnel effect. [14]

Inside a new exotic crystal, physicist Martin Mourigal has observed strong indications of "spooky" action, and lots of it. The results of his experiments, if *corroborated over time, would mean that the type of crystal is a rare new material that can house a quantum spin liquid. [13]*

An international team of researchers have found evidence of a mysterious new state of matter, first predicted 40 years ago, in a real material. This state, known as a quantum spin liquid, causes electrons - thought to be indivisible building blocks of nature - to break into pieces. [12]

In a single particle system, the behavior of the particle is well understood by solving the Schrödinger equation. Here the particle possesses wave nature characterized by the de Broglie wave length. In a many particle system, on the other hand, the particles interact each other in a quantum mechanical way and behave as if they are "liquid". This is called quantum liquid whose properties are very different from that of the single particle case. [11]

Quantum coherence and quantum entanglement are two landmark features of quantum physics, and now physicists have demonstrated that the two phenomena are "operationally equivalent"—that is, equivalent for all practical purposes, though still conceptually distinct. This finding allows physicists to apply decades of research on entanglement to the more fundamental but less-well-researched concept of coherence, offering the possibility of advancing a wide range of quantum technologies. [10]

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.

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.

Contents

Author: George Rajna

Preface

Physicists are continually looking for ways to unify the theory of relativity, which describes large-scale phenomena, with quantum theory, which describes small-scale phenomena. In a new proposed experiment in this area, two toaster-sized "nanosatellites" carrying entangled condensates orbit around the Earth, until one of them moves to a different orbit with different gravitational field strength. As a result of the change in gravity, the entanglement between the condensates is predicted to degrade by up to 20%. Experimentally testing the proposal may be possible in the near future. [5]

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

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

Three teams find a way to measure frequencies with far better precision than previous techniques

Three teams working independently have found a nearly identical way to boost the resolution of quantum magnetic sensors, allowing frequency measurements with far higher precision than previous techniques. Two teams, one with ETH Zurich, the other based at Ulm University in Germany, have published their results in the journal Science. The third team working at Harvard has yet to publish their results, though they have uploaded a copy of their paper to the arXiv preprint server. Andrew Jordan with the University of Rochester in the U.S. has published a Perspective piece in the same Science issue outlining the work by the teams and notes the "multiple independent discovery," which is interesting in and of itself.

Quantum sensing has become an essential tool for physicists—it measures frequencies in a wide variety of applications. But as has been noted, because it must interact with the environment, degradation occurs. In this new effort, all three teams found the same way to increase the accuracy of such sensing using a classical clock.

The improvement involved measuring a quantum qubit by studying defects in nitrogen vacancies (NVs) in a diamond—such vacancies have a magnetic spring, which makes them sensitive to a magnetic field. In this new effort, the researchers from the three teams isolated the NVs, allowing them to measure and manipulate them. They identified a means to enhance the response of the NV to a magnetic field, leading all three teams to improve their results by making repeated measurements at different time points while keeping track of how much time had passed—courtesy of an external clock to keep the measurements synchronized. This allowed for gathering more frequency information and hence improving accuracy. The researchers report improvements of nine orders of magnitude over previous methods.

The team in Germany took their work further by using their measurement technique to carry out NMR spectroscopy on a tiny sample of polybutene and discovered a problem—the molecules diffused past the NV centers, preventing improved resolution. But as it turned out, the Harvard team came up with a solution to the same problem—getting the technique to work on groups of NV centers in the same diamond. [22]

Quantized magneto-electric effect demonstrated for the first time in topological insulators

The 'quantized magneto-electric effect' has been demonstrated for the first time in topological insulators at TU Wien, which is set to open up new and highly accurate methods of measurement.

A light wave sent through empty space always oscillates in the same direction. However, certain materials can be used to rotate the direction in which the light is oscillating when placed in a magnetic field. This is known as a 'magneto-optical' effect.

After much speculation spanning a long period of time, one variant of this type of effect has now been demonstrated at TU Wien for the first time. Rather than switching the direction of the light wave continually, special materials called 'topological insulators' do so in quantum steps in clearly defined portions. The extent of these quantum steps depends solely on fundamental physical parameters, such as the fine-structure constant. It may soon be possible to measure this constant even more accurately using optical techniques than is currently possible via other methods. The latest findings have now been revealed in the open-access journal Nature Communications.

Topological insulators

"We have been working on materials that can change the direction of oscillation of light for some time now," explains Prof. Andrei Pimenov from the Institute of Solid State Physics at TU Wien. As a general rule, the effect depends on how thick the material is: the larger the distance to be travelled by the light in the material, the larger the angle of rotation. However, this is not the case for the materials that Pimenov's team has now investigated more closely with the assistance of a research group from Würzburg. Their focus has been on 'topological insulators', for which the crucial parameter is the surface rather than the thickness.

Insulators on the inside, electricity can usually be conducted very effectively along the surface of a topological insulator. "Even when sending radiation through a topological insulator, the surface is what makes all the difference," says Pimenov. When light propagates in this material, the oscillation direction of the beam is turned by the surface of the material twice – once when it enters and again when it exits.

What is most remarkable here is that this rotation takes place in particular portions, in quantum steps, rather than being continuous. The interval between these points is not determined by the geometry or by properties of the material and is instead defined only by fundamental natural constants. For example, they can be specified on the basis of the fine-structure constant, which is used to describe the strength of the electromagnetic interaction. This could open up the possibility of measuring natural constants with more precision than has previously been the case and may even lead to new measuring techniques being identified.

Increased measurement precision using special materials

The situation is similar for the quantum Hall effect, which is another quantum phenomenon observed in certain materials, in which case a particular variable (here electrical resistance) can rise only by certain amounts. The quantum Hall effect is currently used for high-precision measurements, with the official standard definition of electrical resistance being based on it. Back in 1985, the Nobel Prize in Physics was awarded for the discovery of the quantum Hall effect.

Topological materials have also already been the subject of a Nobel Prize victory – this time in 2016. It is expected that these latest results will also make it possible for materials with special topological characteristics (in this case topological insulators) to be used for specific technical applications. [21]

Quantum reservoir for microwaves

In a recent experiment at EPFL, a microwave resonator, a circuit that supports electric signals oscillating at a resonance frequency, is coupled to the vibrations of a metallic micro-drum. By actively cooling the mechanical motion close to the lowest energy allowed by quantum mechanics, the micro-drum can be turned into a quantum reservoir - an environment that can shape the states of the microwaves. The findings are published as an advanced publication in Nature Physics.

László Dániel Tóth, Nathan Bernier, and Dr Alexey Feofanov led the research effort in Tobias Kippenberg's Laboratory of Photonics and Quantum Measurements at EPFL, with support from Dr Andreas Nunnenkamp, a theorist at the University of Cambridge, UK.

Microwaves are electromagnetic waves, just like visible light, but with a frequency that is four orders of magnitude smaller. Microwaves form the backbone of several everyday technologies, from microwave ovens and cellular phones to satellite communication, and have recently gained further importance in manipulating quantum information in superconducting circuits—one of the most promising candidates to realize future quantum computers.

The micro-drum, only 30 microns in diameter, 100 nanometers thick and fabricated in the Center of MicroNanotechnology (CMi) at EPFL, constitutes the top plate of a capacitor in a superconducting microwave resonator. The drum's position modulates the resonator's resonance frequency and, conversely, a voltage across the capacitor exerts a force on the micro-drum. Through this bidirectional interaction, energy can be exchanged between mechanical vibrations and the microwave oscillations in the superconducting circuit.

In the experiment, the micro-drum is first cooled close to its lowest energy quantum level by a suitably tuned microwave tone. Every microwave photon (a quantum of light) carries away the energy of a phonon (a quantum of mechanical motion) such that the mechanical energy is reduced.

This cooling process increases the dissipation and turns the micro-drum into a dissipative reservoir for the microwave resonator.

By tuning the interactions between the cavity and the cooled micro-drum, which is now an environment for the microwaves, the cavity can be turned into a microwave amplifier. The most interesting aspect of this amplification process is the added noise, that is, how much random, unwanted fluctuations are added to the amplified signal.

Albeit counter-intuitive, quantum mechanics dictates that this added noise cannot be suppressed completely, even in principle. The amplifier realized in the EPFL experiment operates very close to this limit, therefore it is as "quiet" as it can be. Interestingly, in a different regime, the micro-drum turns the microwave resonator into a maser (or microwave laser).

"There has been a lot of research focus on bringing mechanical oscillators into the quantum regime in the past few years." says Dr. Alexey Feofanov, postdoctoral researcher on the project. "However, our experiment is one of the first which actually shows and harnesses their capabilities for future quantum technologies."

Looking ahead, this experiment enables novel phenomena in cavity optomechanical systems like noiseless microwave routing or microwave entanglement. Generally, it proves that mechanical oscillators can be a useful resource in the rapidly growing field of quantum science and engineering.

Future activities on the emerging research possibilities created by this work will be supported by two recently started EC Horizon 2020 projects: Hybrid Optomechanical Technologies (HOT) and Optomechanical Technologies (OMT), both coordinated at EPFL. [20]

A fundamentally new approach to electrostatic design of materials

Researchers at the Institute of Solid State Physics map out a radically new approach for designing optical and electronic properties of materials in Advanced Materials.

Computational materials design is traditionally used to improve and further develop already existing materials. Simulations grant a deep insight into the quantum mechanical effects which determine material properties. Egbert Zojer and his team at the Institute of Solid State Physics of TU Graz go a decisive step beyond that: they use computer simulations to propose an entirely new concept for controlling the electronic properties of materials. Potentially disturbing influences arising from the regular arrangement of polar elements, so-called collective electrostatic effects, are used by the research group to intentionally manipulate material properties. That this radically new approach also works for three-dimensional materials has been demonstrated by the Graz team in Advanced Materials, which according to Google Scholar is internationally the most important journal in the field of materials research.

Manipulation of the energetic materials landscape

"The basic approach of the electrostatic design concept is to modify the electronic states of semiconductors via the periodic arrangement of dipolar groups. In this way we are able to locally manipulate energy levels in a controlled way. In doing so, we do not try to find ways to bypass such effects which are inevitable especially at interfaces. Rather, we make deliberate use of them for our own purposes," explains Egbert Zojer.

This topic has been in the focus of the research of the Zojer group already for some time. The first step was the electrostatic design of molecular monolayers, for example on gold electrodes. Experiments have shown that the predicted energy shifts within the layers actually take place and that charge transport through monolayers can be deliberately modulated. Also, the electronic states of two-dimensional materials, such as graphene, can be controlled by means of collective electrostatic effects. In the publication in Advanced Materials, doctoral student Veronika Obersteiner, Egbert Zojer and other colleagues from the team demonstrate the full potential of the concept by extending it to three-dimensional materials.

"For the example of three-dimensional covalent organic networks, we show how – by means of collective electrostatic effects – the energy landscape within three-dimensional bulk material can be manipulated such that spatially confined pathways for electrons and holes can be realised. In this way charge carriers can, for instance, be separated and the electronic properties of the material can be designed as desired," says Zojer.

The concept is especially interesting for solar cells. In classical organic solar cells, chemically different building blocks, so-called donors and acceptors, are used to separate the photogenerated electron-hole pairs. In the approach proposed here, the necessary local shift of energy levels occurs due to the periodic arrangement of polar groups. The semiconducting areas onto which the electrons and holes are shifted are chemically identical. "In this way, we can quasi-continuously and efficiently fine tune the energy levels by varying the dipole density. This work is the climax to our intensive research on the electrostatic design of materials," says Zojer.

Electrostatic design in 3-D systems can also enable the realization of complex quantum structures, such as quantum-cascades and quantum-checkerboards. "Only the imagination of the materials designer can set limits to our concept," says Zojer. [19]

Sandwiched between superconductors, graphene adopts exotic electronic states

In normal conductive materials such as silver and copper, electric current flows with varying degrees of resistance, in the form of individual electrons that ping-pong off defects, dissipating energy as they go. Superconductors, by contrast, are so named for their remarkable ability to conduct electricity without resistance, by means of electrons that pair up and move through a material as one, generating no friction.

Now MIT physicists have found that a flake of graphene, when brought in close proximity with two superconducting materials, can inherit some of those materials' superconducting qualities. As graphene is sandwiched between superconductors, its electronic state changes dramatically, even at its center.

The researchers found that graphene's electrons, formerly behaving as individual, scattering particles, instead pair up in "Andreev states"—a fundamental electronic configuration that allows a conventional, nonsuperconducting material to carry a "supercurrent," an electric current that flows without dissipating energy.

Their findings, published this week in Nature Physics, are the first investigation of Andreev states due to superconductivity's "proximity effect" in a two-dimensional material such as graphene.

Down the road, the researchers' graphene platform may be used to explore exotic particles, such as Majorana fermions, which are thought to arise from Andreev states and may be key particles for building powerful, error-proof quantum computers.

"There is a huge effort in the condensed physics community to look for exotic quantum electronic states," says lead author Landry Bretheau, a postdoc in MIT's Department of Physics. "In particular, new particles called Majorana fermions are predicted to emerge in graphene that is connected to superconducting electrodes and exposed to large magnetic fields. Our experiment is promising, as we are unifying some of these ingredients."

Landry's MIT co-authors are postdoc Joel I-Jan Wang, visiting student Riccardo Pisoni, and associate professor of physics Pablo Jarillo-Herrero, along with Kenji Watanabe and Takashi Taniguchi of the National Institute for Materials Science, in Japan.

The superconducting proximity effect

In 1962, the British physicist Brian David Josephson predicted that two superconductors sandwiching a nonsuperconducting layer between them could sustain a supercurrent of electron pairs, without any external voltage.

As a whole, the supercurrent associated with the Josephson effect has been measured in numerous experiments. But Andreev states—considered the microscopic building blocks of a supercurrent—have been observed only in a handful of systems, such as silver wires, and never in a two-dimensional material.

Bretheau, Wang, and Jarillo-Herrero tackled this issue by using graphene—an ultrathin sheet of interlinked carbon atoms—as the nonsuperconducting material. Graphene, as Bretheau explains, is an extremely "clean" system, exhibiting very little scattering of electrons. Graphene's extended, atomic configuration also enables scientists to measure graphene's electronic Andreev states as the material comes in contact with superconductors. Scientists can also control the density of electrons in graphene and investigate how it affects the superconducting proximity effect.

The researchers exfoliated a very thin flake of graphene, just a few hundred nanometers wide, from a larger chunk of graphite, and placed the flake on a small platform made from a crystal of boron nitride overlaying a sheet of graphite. On either end of the graphene flake, they placed an electrode made from aluminum, which behaves as a superconductor at low temperatures. They then placed the entire structure in a dilution refrigerator and lowered the temperature to 20 millikelvin—well within aluminum's superconducting range.

"Frustrated" states

In their experiments, the researchers varied the magnitude of the supercurrent flowing between the superconductors by applying a changing magnetic field to the entire structure. They also applied an external voltage directly to graphene, to vary the number of electrons in the material.

Under these changing conditions, the team measured the graphene's density of electronic states while the flake was in contact with both aluminum superconductors. Using tunneling spectroscopy, a common technique that measures the density of electronic states in a conductive sample, the researchers were able to probe the graphene's central region to see whether the superconductors had any effect, even in areas where they weren't physically touching the graphene.

The measurements indicated that graphene's electrons, which normally act as individual particles, were pairing up, though in "frustrated" configurations, with energies dependent on magnetic field.

"Electrons in a superconductor dance harmoniously in pairs, like a ballet, but the choreography in the left and right superconductors can be different," Bretheau says. "Pairs in the central graphene are frustrated as they try to satisfy both ways of dancing. These frustrated pairs are what physicists know as Andreev states; they are carrying the supercurrent."

Bretheau and Wang found Andreev states vary their energy in response to a changing magnetic field. Andreev states are more pronounced when graphene has a higher density of electrons and there is a stronger supercurrent running between electrodes.

"[The superconductors] are actually giving graphene some superconducting qualities," Bretheau says. "We found these electrons can be dramatically affected by superconductors."

While the researchers carried out their experiments under low magnetic fields, they say their platform may be a starting point for exploring the more exotic Majorana fermions that should appear under high magnetic fields.

"There are proposals for how to use Majorana fermions to build powerful quantum computers," Bretheau says. "These particles could be the elementary brick of topological quantum computers, with very strong protection against errors. Our work is an initial step in this direction." [18]

Electrons losing weight

The measured mass of electrons in solids is always larger than the value predicted by theory. The reason for this is that theoretical calculations do not account properly for various interactions with other electrons or lattice vibrations – that "dress" the electrons. EPFL scientists have now carried out a study on a lithium-containing copper oxide and have found that its electrons are 2.5 times lighter than was predicted by theoretical calculations. The work is published in Physical Review Letters and has made the cover.

The lab of Marco Grioni at EPFL used a spectroscopy technique called ARPES (angle-resolved photoemission spectroscopy), which allows researchers to "track" electron behavior in a solid material. In this case, the solid material was a copper oxide, a member of the transition-metal oxide family of materials, which have wide-ranging applications for their electronic, magnetic and catalytic properties. In this type of copper oxide Cu atoms have two different values of valence, making it a "mixed-valence" compound.

The researchers used ARPES to measure the energy of the electron bands in the copper oxide. This then helped them calculate the mass of its electrons. Simply put, the broader the band, the smaller the electron's mass.

Running the measurements, the scientists found that the copper oxide's electrons are actually 2.5 times lighter than the values given by theoretical predictions. "This is rather unique and unexpected," says Marco Grioni. "It goes against a widely accepted tenet of many-body theory that says that correlation effects generally yield narrower bands and larger electron masses."

The authors state that present-day electronic structure calculation techniques may provide an intrinsically inappropriate description of ligand-to-d hybridizations in late transition metal oxides. [17]

Physicists create 'negative mass'

Washington State University physicists have created a fluid with negative mass, which is exactly what it sounds like. Push it, and unlike every physical object in the world we know, it doesn't accelerate in the direction it was pushed. It accelerates backwards.

The phenomenon is rarely created in laboratory conditions and can be used to explore some of the more challenging concepts of the cosmos, said Michael Forbes, a WSU assistant professor of physics and astronomy and an affiliate assistant professor at the University of Washington. The research appears today in the journal Physical Review Letters, where it is featured as an "Editor's Suggestion."

Hypothetically, matter can have negative mass in the same sense that an electric charge can be either negative or positive. People rarely think in these terms, and our everyday world sees only the positive aspects of Isaac Newton's Second Law of Motion, in which a force is equal to the mass of an object times its acceleration, or F=ma.In other words, if you push an object, it will accelerate in the direction you're pushing it. Mass will accelerate in the direction of the force.

"That's what most things that we're used to do," said Forbes, hinting at the bizarreness to come. "With negative mass, if you push something, it accelerates toward you."

Conditions for negative mass

He and his colleagues created the conditions for negative mass by cooling rubidium atoms to just a hair above absolute zero, creating what is known as a Bose-Einstein condensate. In this state, predicted by Satyendra Nath Bose and Albert Einstein, particles move extremely slowly and, following the principles of quantum mechanics, behave like waves. They also synchronize and move in unison as what is known as a superfluid, which flows without losing energy.

Led by Peter Engels, WSU professor of physics and astronomy, researchers on the sixth floor of Webster Hall created these conditions by using lasers to slow the particles, making them colder, and allowing hot, high energy particles to escape like steam, cooling the material further.

The lasers trapped the atoms as if they were in a bowl measuring less than a hundred microns across. At this point, the rubidium superfluid has regular mass. Breaking the bowl will allow the rubidium to rush out, expanding as the rubidium in the center pushes outward.

To create negative mass, the researchers applied a second set of lasers that kicked the atoms back and forth and changed the way they spin. Now when the rubidium rushes out fast enough, if behaves as if it has negative mass."Once you push, it accelerates backwards," said Forbes, who acted as a theorist analyzing the system. "It looks like the rubidium hits an invisible wall."

Avoiding underlying defects

The technique used by the WSU researchers avoids some of the underlying defects encountered in previous attempts to understand negative mass.

"What's a first here is the exquisite control we have over the nature of this negative mass, without any other complications" said Forbes. Their research clarifies, in terms of negative mass, similar behavior seen in other systems.This heightened control gives researchers a new tool to engineer experiments to study analogous physics in astrophysics, like neutron stars, and cosmological phenomena like black holes and dark energy, where experiments are impossible."It provides another environment to study a fundamental phenomenon that is very peculiar," Forbes said. [16]

Researchers obtain supersolidity state experimentally

When matter is cooled to near absolute zero, intriguing phenomena emerge. These include supersolidity, where crystalline structure and frictionless flow occur together. ETH researchers have succeeded in realising this strange state experimentally for the first time.

Solid, liquid or gas are the three clearly defined states of matter. It is difficult to imagine that substances could simultaneously exhibit properties of two of these states. Yet, precisely such a phenomenon is possible in the realm of quantum physics, where matter can display behaviours that seem mutually exclusive.

Supersolidity is one example of such a paradoxical state. In a supersolid, atoms are arranged in a crystalline pattern while at the same time behaving like a superfluid, in which particles move without friction.

Until now, supersolidity was merely a theoretical construct. But in the latest issue of Nature, a group of researchers led by Tilman Esslinger, professor of quantum optics at the Institute for Quantum Electronics, and Tobias Donner, senior scientist at the same institute, report the successful production of a supersolid state.

The researchers introduced a small amount of rubidium gas into a vacuum chamber and cooled it to a temperature of a few billionths of a kelvin above absolute zero, such that the atoms condensed into what is known as a Bose-Einstein condensate. This is a peculiar quantum-mechanical state that behaves like a superfluid.

Researchers obtain supersolidity state experimentally

Detail view of the experimental set-up, showing the four mirrors arranged in opposing pairs, each creating an optical resonance chamber. Credit: ETH Zurich

The researchers placed this condensate in a device with two intersecting optical resonance chambers, each consisting of two tiny opposing mirrors. The condensate was then illuminated with laser light, which was scattered into both of these two chambers. The combination of these two light fields in the resonance chambers caused the atoms in the condensate to adopt a regular, crystal-like structure. The condensate retained its superfluid properties – the atoms in the condensate were still able to flow without any energy input, at least in one direction, which is not possible in a "normal" solid.

"We were able to produce this special state in the lab thanks to a sophisticated setup that allowed us to make the two resonance chambers identical for the atoms," explains Esslinger.

From theoretical concept to experimental reality

With their experiment, the physicists in the team of Esslinger and Donner realised a concept theorised by scientists including British physicist David Thouless. In 1969, he postulated that a superfluid could also have a crystalline structure. Theoretical considerations led to the conclusion that this phenomenon could be most easily demonstrated with helium cooled to just a few kelvins above absolute zero. In 2004, a U.S. group reported that they had found experimental evidence for such a state, but later attributed their findings to surface effects of helium. "Our work has now successfully implemented Thouless's ideas," explains Donner. "We didn't use helium, however, but a Bose–Einstein condensate."

A second, independent study on the same topic appears in the same issue of Nature: a group of researchers led by Wolfgang Ketterle at MIT announced last autumn – shortly after the researchers at ETH – that they had also succeeded in finding evidence of supersolidity, using a different experimental approach. [15]

Partnership at a distance: Deep-frozen helium molecules

Helium atoms are loners. Only if they are cooled down to an extremely low temperature do they form a very weakly bound molecule. In so doing, they can keep a tremendous distance from each other thanks to the quantum-mechanical tunnel effect. As atomic physicists in Frankfurt have now been able to confirm, over 75 percent of the time they are so far apart that their bond can be explained only by the quantum-mechanical tunnel effect.

The binding energy in the helium molecule amounts to only about a billionth of the binding energy in everyday molecules such as oxygen or nitrogen. In addition, the molecule is so huge that small viruses or soot particles could fly between the atoms. This is due, physicists explain, to the quantum-mechanical "tunnel effect". They use a potential well to illustrate the bond in a conventional molecule. The atoms cannot move further away from each other than the "walls" of this well. However, in quantum mechanics the atoms can tunnel into the walls. "It's as if two people each dig a tunnel on their own side with no exit", explains Professor Reinhard Dörner of the Institute of Nuclear Physics at Goethe University Frankfurt.

Dörner's research group has produced this helium molecule in the laboratory and studied it with the help of the COLTRIMS reaction microscope developed at the University. The researchers were able to determine the strength of the bond with a level of precision not previously achieved and measured the distance between the two atoms in the molecule. "The helium molecule is something of a touchstone for quantum-mechanical theories, as the value of the binding energy theoretically predicted is heavily dependent on how accurately all physical and quantum-mechanical effects were taken into account", explains Dörner.

Even the theory of relativity, which is otherwise mainly required for astronomical calculations, had to be incorporated here. "If even just a small mistake occurs, the calculations produce major deviations or even indicate that a helium molecule cannot exist at all", says Dörner. The precision measurements performed by his research group will serve as a benchmark for future experiments.

Two years spent taking measurements in the cellar

Dörner's research group began investigating the helium molecule back in 2009, when the German Research Foundation awarded him a Reinhart Koselleck Project and funding to the tune of € 1.25 million. "This type of funding is risk capital, as it were, with which the German Research Foundation supports experiments with a long lead time", explains Dörner. He was thus able to design and set up the first experiments with his group. Initial results were achieved by Dr. Jörg Voigtsberger in the framework of his doctoral dissertation. "In the search for atoms which 'live in the tunnel', Jörg Voigtsberger spent two years of his life in the cellar", recalls Dr. Till Jahnke, senior lecturer and Voigtberger's supervisor at the time. It is there, in the cellar, that the laser laboratory of the atomic physics group is housed.

Stefan Zeller, the next doctoral researcher, considerably improved the equipment with the help of Dr. Maksim Kunitski and increased measurement precision still further. To do so, one of his tasks was to shoot at the very weakly bonded helium molecule with FLASH, the free-electron laser at the DESY research centre in Hamburg and the largest "photon canon" in Germany. "Stefan Zeller's work was remarkable. It was his untiring effort, his excellent experimental research skills and his ability not to be disheartened by temporary setbacks which made our success possible at all", remarks Professor Dörner, Zeller's doctoral supervisor.

Already beforehand the results have attracted considerable interest at national and international level. They will now appear in the renowned journal Proceedings of the National Academy of Sciences (PNAS) and are also part of the research work for which the group was awarded the Helmholtz Prize 2016. [14]

'Spooky' sightings in crystal point to extremely rare quantum spin liquid

Inside a new exotic crystal, physicist Martin Mourigal has observed strong indications of "spooky" action, and lots of it. The results of his experiments, if corroborated over time, would mean that the type of crystal is a rare new material that can house a quantum spin liquid.

Currently, only a small handful of materials are believed to possibly have these properties. This new crystal was synthesized for the first time only a year ago. Corroboration by other physicists of Mourigal's newly produced experimental data could take a decade or longer.

Confused? Meet quantum physics

A "liquid" found inside a solid object may sound confusing to many people.

Welcome to quantum materials, part of the twilight zone called quantum physics, which scientists have been struggling for a century to grasp a nanometer at a time. Though much about it is yet undiscovered, quantum physics describes the underlying reality of matter.

The workings of computers, cell phones, superconductors and MRI machines are based on it. But its laws about the atomic realm defy human perception of what is real, and some sound so preposterous that they have become popular science brain teasers.

'Liquid' in 'spooky' entanglement

Take quantum entanglement, the core of Mourigal's research on the crystal: If two particles, electrons for example, become entangled, they can be physically separated by many miles, and still be intimately linked to one another. Actions applied to one particle then instantaneously effect the other.

At first, this theory was too weird even for the father of relativity, Albert Einstein, who lampooned it as "spooky action at a distance."

Entanglement has since been proven in experiments, but now scientists like Mourigal, an experimental physicist at the Georgia Institute of Technology, and his team, have taken it much farther. The synthetic crystal he has examined, an ytterbium compound with the formula YbMgGaO4, is likely brimming with observable 'spooky' connections.

Mourigal, former postdoctoral fellow Joseph Paddison and graduate student Marcus Daum published their observations in the journal Nature Physics on Monday, December 5, 2016. They collaborated with colleagues at the University of Tennessee and Oak Ridge National Laboratory. Work was funded by the National Science Foundation and the U.S. Department of Energy.

Quantum computing dreams

This massive 'spooky' entanglement makes a system of electrons a quantum spin "liquid." The term is not meant in the everyday sense, as in water. Here, it describes the collective nature of electrons' spins in the crystal.

"In a spin 'liquid,' the directions of the spins are not tidily aligned, but frenzied, although the spins are interconnected, whereas in a spin 'solid' the spin directions have a neat organization," Mourigal said.

If the discovery stands, it could open a door to hundreds of yet unknown quantum spin liquid materials that physicists say must exist according to theory and mathematical equations. In the distant future, new quantum materials could become, by today's standards, virtual sorcerer's stones in quantum computing engineers' hands.

Beijing's ytterbium crystal success?

The ytterbium crystal was first synthesized a year ago by scientists in China, where the government in Beijing has invested heavily in hopes of creating synthetic quantum materials with novel properties. It appears they may have now succeeded, said Mourigal, an assistant professor at Georgia Tech's School of Physics.

"Imagine a state of matter where this entanglement doesn't involve two electrons but involves, three, five, 10 or 10 billion particles all in the same system," Mourigal said. "You can create a very, very exotic state of matter based on the fact that all these particles are entangled with each other. There are no individual particles anymore, but one huge electron ensemble acting collectively."

One of the only previously observed apparent quantum spin liquids occurs in a natural crystal called herbertsmithite, an emerald green stone found in 1972 in a mine in Chile. It was named after mineralogist Herbert Smith, who died nearly 20 years prior to the discovery.

Researchers observed its apparent spin liquid nature in 2012 after Massachusetts Institute of Technology scientists succeeded at reproducing a purified piece of the crystal in their lab.

Encyclopedia of spin liquids

That initial discovery was just the beginning of an Odyssey. Because of its chemical makeup, herbertsmithite produces just one single entanglement scheme. Physics math says there must be myriads more.

"Finding herbertsmithite was like saying, 'animals exist.' But there are so many different species of animals, or mammals, or fish, reptiles and birds," Mourigal said. "Now that we have found one, we are looking for different kinds of spin liquids."

The more spin liquids experimental physicists confirm, the more theoretical physicists will be able to use them to bend their minds around quantum physics. "It's important to create the encyclopedia of them," Mourigal said. "This new crystal may be only our second or third entry."

What neutron scattering revealed

Physicists from the University of Tennessee succeeded in replicating the original ytterbium crystal, and Mourigal examined it at Oak Ridge National Laboratory (ORNL), where it was cooled down to a temperature of -273.09 degrees Celsius (0.06 degrees Kelvin).

The cooling slowed the natural motion of the atoms to a near stop, which allowed the researchers to observe the electron spins' dance around the Ytterbium (Yb) atoms in the $YbMgGaO_4$ crystal. They used a powerful superconducting magnet to line the spins up in an orderly fashion to create a starting point for their observations.

"Then we removed the magnetic field, and let them go back to their special kind of wiggling," Mourigal said. His team carried out the observations at the ORNL Spallation Neutron Source, a U.S. Department of Energy Office of Science User Facility. SNS has about the power and size of a particle supercollider, and allowed the scientists to watch the concert of electrons' spins by bombarding them with neutrons.

Normally, when one electron flips its spin, researchers would expect it to create a neat chain reaction, resulting in a wave going through the crystal. The wave of electron spins flipping in sequence might look something like fans at a football game standing and sitting back down to make a wave go around the stadium.

But something odd happened. "This jumbly kind of spin wave broke down into many other waves, because everything is collective, everything is entangled," Mourigal said. "It was a continuum of excitations, but breaking down across many electrons at once."

It was qualitatively similar to what was observed using the same technique on herbertsmithite.

Nobel Prize topology donut

To authenticate the observations made by Mourigal's team, theoretical physicists will have to crunch the data with methods that, in part, rely on topology, a focus of the 2016 Nobel Prize in Physics. Mourigal thinks chances are they will pass muster. "At first glance, this material is screaming, 'I'm a quantum spin liquid,'" he said.

But it must undergo a years-long battery of stringent mathematical tests. The theoretical physicists will wrap the data around a mathematical "donut" to confirm whether or not it is a quantum spin liquid.

"That's meant seriously," Mourigal said. "As a mathematical mental exercise, they virtually spread the spin liquid around a donut shape, and the way it responds to being on a donut tells you something about the nature of that spin liquid."

Though entangled particles appear to defy space and time, the shape of space they occupy affects the nature of the entanglement pattern.

The possibility of a quantum spin liquid was first demonstrated in the 1930s, but only using atoms placed in a straight line. Physicists have been searching in the decades since for materials containing them. [13]

New state of matter detected in a two-dimensional material

The researchers, including physicists from the University of Cambridge, measured the first signatures of these fractional particles, known as Majorana fermions, in a two-dimensional material with a structure similar to graphene. Their experimental results successfully matched with one of the main theoretical models for a quantum spin liquid, known as a Kitaev model. The results are reported in the journal Nature Materials.

Quantum spin liquids are mysterious states of matter which are thought to be hiding in certain magnetic materials, but had not been conclusively sighted in nature.

The observation of one of their most intriguing properties—electron splitting, or fractionalisation—in real materials is a breakthrough. The resulting Majorana fermions may be used as building blocks of quantum computers, which would be far faster than conventional computers and would be able to perform calculations that could not be done otherwise.

"This is a new quantum state of matter, which has been predicted but hasn't been seen before," said Dr Johannes Knolle of Cambridge's Cavendish Laboratory, one of the paper's co-authors.

In a typical magnetic material, the electrons each behave like tiny bar magnets. And when a material is cooled to a low enough temperature, the 'magnets' will order themselves, so that all the north magnetic poles point in the same direction, for example.

But in a material containing a spin liquid state, even if that material is cooled to absolute zero, the bar magnets would not align but form an entangled soup caused by quantum fluctuations.

"Until recently, we didn't even know what the experimental fingerprints of a quantum spin liquid would look like," said paper co-author Dr Dmitry Kovrizhin, also from the Theory of Condensed Matter group of the Cavendish Laboratory. "One thing we've done in previous work is to ask, if I were performing experiments on a possible quantum spin liquid, what would I observe?"

Knolle and Kovrizhin's co-authors, led by the Oak Ridge National Laboratory, used neutron scattering techniques to look for experimental evidence of fractionalisation in crystals of ruthenium chloride

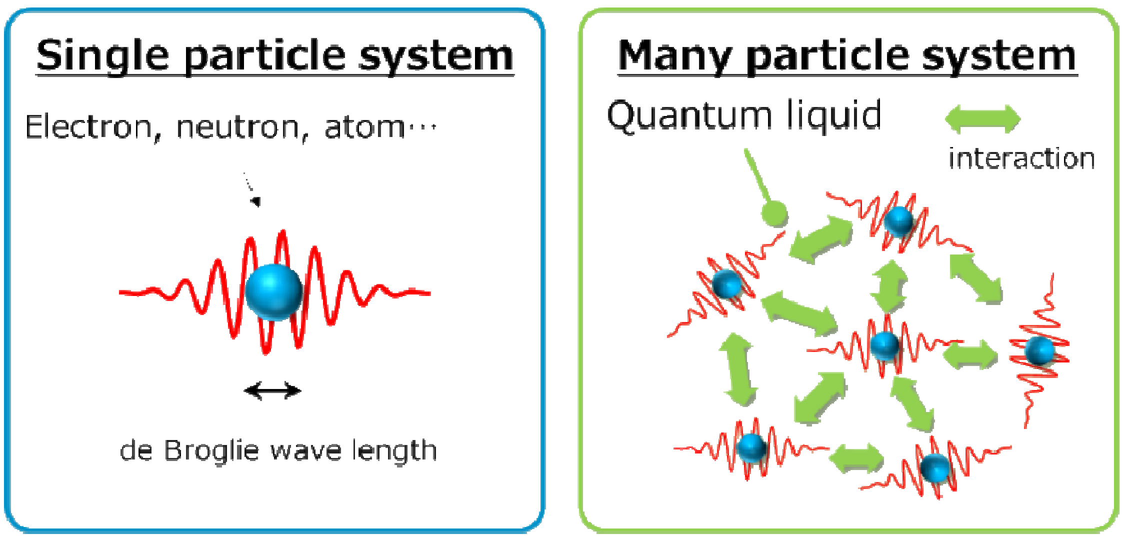
(RuCl3). The researchers tested the magnetic properties of the RuCl3 crystals by illuminating them with neutrons, and observing the pattern of ripples that the neutrons produced on a screen.

A regular magnet would create distinct sharp spots, but it was a mystery what sort of pattern the Majorana fermions in a quantum spin liquid would make. The theoretical prediction of distinct signatures by Knolle and his collaborators in 2014 match well with what experimentalists observed on the screen, providing for the first time direct evidence of a quantum spin liquid and the fractionalisation of electrons in a two dimensional material.

"This is a new addition to a short list of known quantum states of matter," said Knolle.

"It's an important step for our understanding of quantum matter," said Kovrizhin. "It's fun to have another new quantum state that we've never seen before - it presents us with new possibilities to try new things." [12]

Mysterious behavior of quantum liquid elucidated, a world first



In cooperation with researchers from Osaka City University and the University of Tokyo, researchers at Osaka University, through their precise measurement of current fluctuations in quantum liquids in an artificial atom created by nanotechnology, succeeded in elucidating theoretically-predicted behavior of quantum liquid in a non-equilibrium regime.

Quantum liquids are macroscopic ensembles of interacting particles dense enough for quantum statistics to manifest itself. For fermions, it is known that, around equilibrium, all the quantum liquids can be universally described within a single theory, so called Landau Fermi liquid theory. The central idea is that they can be treated as an ensemble of free "quasi-particles". This conceptual framework has been applied to many physical systems, such as liquid helium 3, normal metals, heavy fermions, neutron stars, and cold gases, where their properties in the linear-response regime have been successfully described by the theory. However, non-equilibrium properties beyond this regime have still to be established and remain a key issue of many-body physics.

Kensuke Kobayashi, Meydi Ferrier, Tomonori Arakawa, Tokuro Hata, Ryo Fujiwara at Osaka University in collaboration with Akira Oguri at Osaka City University and Rui Sakano at the University of Tokyo together with Raphaëlle Delagrange, Raphaël Weil, Richard Deblock at Laboratoire de Physique des Solides, CNRS, Univ. Paris-Sud, Université Paris Saclay show a precise experimental demonstration of Landau Fermi-liquid theory extended to the non-equilibrium regime in a 0-D system. Combining transport and sensitive current noise measurements, they have identified the SU(2) and SU(4) symmetries of quantum liquid in a carbon nanotube tuned in the Kondo regime. They find that, while the electronic transport is well described by the free quasi-particle picture around equilibrium just as the Fermi liquid theory tells us, a two-particle scattering process due to residual interaction shows up in the non-equilibrium regime. The result, in perfect agreement with theory, provides a strong quantitative experimental background for further developments of the many-body physics. Moreover, they discovered a new scaling law for the effective charge, signaling as-yet-unknown universality in the non-equilibrium regime.

This achievement will open up a new way to explore quantum many-body physics through fluctuations, which stands on firm ground even out of equilibrium beyond the conventional Landau Fermi liquid theory. The newly discovered universality would trigger a vast theoretical effort. [11]

Physicists find quantum coherence and quantum entanglement are two sides of the same coin

Quantum coherence and quantum entanglement are two landmark features of quantum physics, and now physicists have demonstrated that the two phenomena are "operationally equivalent"—that is, equivalent for all practical purposes, though still conceptually distinct. This finding allows physicists to apply decades of research on entanglement to the more fundamental but less-well-researched concept of coherence, offering the possibility of advancing a wide range of quantum technologies.

Close relatives with the same roots

Although physicists have known that coherence and entanglement are close relatives, the exact relationship between the two resources has not been clear.

It's well-known that quantum coherence and quantum entanglement are both rooted in the superposition principle—the phenomenon in which a single quantum state simultaneously consists of multiple states—but in different ways. Quantum coherence deals with the idea that all objects have wave-like properties. If an object's wave-like nature is split in two, then the two waves may coherently interfere with each other in such a way as to form a single state that is a superposition of the two states. This concept of superposition is famously represented by Schrödinger's cat, which is both dead and alive at the same time when in its coherent state inside a closed box. Coherence also lies at the heart of quantum computing, in which a qubit is in a superposition of the "0" and "1" states, resulting in a speed-up over various classical algorithms. When such a state experiences decoherence, however, all of its quantumness is typically lost and the advantage vanishes.

The second phenomenon, quantum entanglement, also involves superposition. But in this case, the states in a superposition are the shared states of two entangled particles rather than those of the two split waves of a single particle. The intrigue of entanglement lies in the fact that the two entangled particles are so intimately correlated that a measurement on one particle instantly affects the other particle, even when separated by a large distance. Like coherence, quantum entanglement also plays an essential role in quantum technologies, such as quantum teleportation, quantum cryptography, and super dense coding.

Converting one to the other

In a paper to be published in Physical Review Letters, physicists led by Gerardo Adesso, Associate Professor at the University of Nottingham in the UK, with coauthors from Spain and India, have provided a simple yet powerful answer to the question of how these two resources are related: the scientists show that coherence and entanglement are quantitatively, or operationally, equivalent, based on their behavior arising from their respective resource theories.

The physicists arrived at this result by showing that, in general, any nonzero amount of coherence in a system can be converted into an equal amount of entanglement between that system and another initially incoherent one. This discovery of the conversion between coherence and entanglement has several important implications. For one, it means that quantum coherence can be measured through entanglement. Consequently, all of the comprehensive knowledge that researchers have obtained about entanglement can now be directly applied to coherence, which in general is not nearly as well-researched (outside of the area of quantum optics). For example, the new knowledge has already allowed the physicists to settle an important open question concerning the geometric measure of coherence: since the geometric measure of entanglement is a "full convex monotone," the same can be said of the associated coherence measure. As the scientists explained, this is possible because the new results allowed them to define and quantify one resource in terms of the other.

"The significance of our work lies in the fact that we prove the close relation between entanglement and coherence not only qualitatively, but on a quantitative level," coauthor Alex Streltsov, of ICFO-The Institute of Photonic Sciences in Barcelona, told Phys.org. "More precisely, we show that any quantifier of entanglement gives rise to a quantifier of coherence. This concept allowed us to prove that the geometric measure of coherence is a valid coherence quantifier, thus answering a question left open in several previous works."

While the results show that coherence and entanglement are operationally equivalent, the physicists explain that this doesn't mean that are the exact same thing, as they are still conceptually different ideas.

"Despite having the same roots of origin, namely quantum superposition, coherence and entanglement are conceptually different," said coauthors Uttam Singh, Himadri Dhar, and Manabendra Bera at the Harish-Chandra Research Institute in Allahabad, India. "For example, coherence can be present in single quantum systems, where entanglement is not well-defined. Also, coherence is defined with respect to a given basis, while entanglement is invariant under local basis changes. In all, we believe coherence and entanglement are operationally equivalent but conceptually different."

Future quantum connections

The operational equivalence of coherence and entanglement will likely have a far-reaching impact on areas ranging from quantum information theory to more nascent fields such as quantum biology and nanoscale thermodynamics. In the future, the physicists plan to investigate whether coherence and entanglement might also be interconverted into a third resource—that of quantum discord, which, like entanglement, is another type of quantum correlation between two systems.

"Our future plans are diverse," Adesso said. "On the theoretical side, we are working to construct a unified framework to interpret, classify and quantify all different forms of quantum resources, including and beyond entanglement and coherence, and highlight the interlinks among them from an operational perspective. This will allow us to navigate the hierarchy of quantumness indicators in composite systems with a common pilot, and to appreciate which particular ingredients are needed in various informational tasks.

"On the practical side, we are investigating experimentally friendly schemes to detect, quantify, and preserve coherence, entanglement and other quantum correlations in noisy environments. More fundamentally, we hope these results will inspire us to devise scalable and efficient methods to convert between different quantum resources for technological applications, and bring us closer to understanding where the boundaries of the quantum world ultimately lie in realistic scenarios." [10]

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]

Quantum Biology

The human body is a constant flux of thousands of chemical/biological interactions and processes connecting molecules, cells, organs, and fluids, throughout the brain, body, and nervous system. Up until recently it was thought that all these interactions operated in a linear sequence, passing on information much like a runner passing the baton to the next runner. However, the latest findings in quantum biology and biophysics have discovered that there is in fact a tremendous degree of coherence within all living systems.

Quantum Consciousness

Extensive scientific investigation has found that a form of quantum coherence operates within living biological systems through what is known as biological excitations and biophoton emission. What this means is that metabolic energy is stored as a form of electromechanical and electromagnetic excitations. These coherent excitations are considered responsible for generating and maintaining long-range order via the transformation of energy and very weak electromagnetic signals. After nearly twenty years of experimental research, Fritz-Albert Popp put forward the hypothesis that biophotons are emitted from a coherent electrodynamics field within the living system.

What this means is that each living cell is giving off, or resonating, a biophoton field of coherent energy. If each cell is emitting this field, then the whole living system is, in effect, a resonating field-a ubiquitous nonlocal field. And since biophotons are the entities through which the living system communicates, there is near-instantaneous intercommunication throughout. And this, claims Popp, is the basis for coherent biological organization -- referred to as quantum coherence. This discovery led Popp to state that the capacity for evolution rests not on aggressive struggle and rivalry but on the capacity for communication and cooperation. In this sense the built-in capacity for species evolution is not based on the individual but rather living systems that are interlinked within a coherent whole: Living systems are thus neither the subjects alone, nor objects isolated, but both subjects and objects in a mutually communicating universe of meaning. . . . Just as the cells in an organism take on different tasks for the whole, different populations enfold information not only for themselves, but for all other organisms, expanding the consciousness of the whole, while at the same time becoming more and more aware of this collective consciousness.

Quantum Cognition

Human Perception

A Bi-stable perceptual phenomenon is a fascinating topic in the area of perception. If a stimulus has an ambiguous interpretation, such as a Necker cube, the interpretation tends to oscillate across time. Quantum models have been developed to predict the time period between oscillations and how these periods change with frequency of measurement. Quantum theory has also been used for modeling Gestalt perception, to account for interference effects obtained with measurements of ambiguous figures. [6]

Human memory

The hypothesis that there may be something quantum-like about the human mental function was put forward with “Spooky Activation at Distance” formula which attempted to model the effect that when a word’s associative network is activated during study in memory experiment, it behaves like a quantum-entangled system. Models of cognitive agents and memory based on quantum collectives have been proposed by Subhash Kak. But he also points to specific problems of limits on observation and control of these memories due to fundamental logical reasons. [6]

Knowledge representation

Concepts are basic cognitive phenomena, which provide the content for inference, explanation, and language understanding. Cognitive psychology has researched different approaches for understanding concepts including exemplars, prototypes, and neural networks, and different fundamental problems have been identified, such as the experimentally tested non classical behavior for the conjunction and disjunction of concepts, more specifically the Pet-Fish problem or guppy effect, and the overextension and under extension of typicality and membership weight for conjunction and disjunction. By and large, quantum cognition has drawn on quantum theory in three ways to model concepts.

Exploit the contextuality of quantum theory to account for the contextuality of concepts in cognition and language and the phenomenon of emergent properties when concepts combine.

Use quantum entanglement to model the semantics of concept combinations in a non-decompositional way, and to account for the emergent properties/associates/inferences in relation to concept combinations.

Use quantum superposition to account for the emergence of a new concept when concepts are combined, and as a consequence put forward an explanatory model for the Pet-Fish problem situation, and the overextension and under extension of membership weights for the conjunction and disjunction of concepts. The large amount of data collected by Hampton on the combination of two concepts can be modeled in a specific quantum-theoretic framework in Fock space where the observed deviations from classical set (fuzzy set) theory, the above mentioned over- and under-extension of membership weights, are explained in terms of contextual interactions, superposition, interference, entanglement and emergence. And, more, a cognitive test on a specific concept combination has been performed which directly reveals, through the violation of Bell's inequalities, quantum entanglement between the component concepts. [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." [9]

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]

Dark Matter and Energy

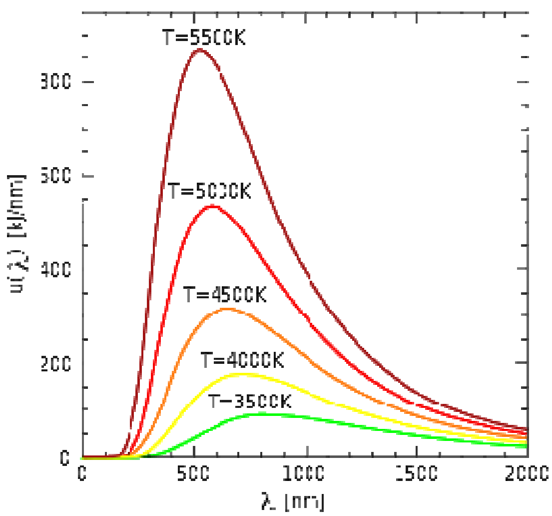
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant level. It is otherwise hypothesized to simply be matter that is not reactant to light. Instead, the existence and properties of dark matter are inferred from its gravitational effects on visible matter, radiation, and the large-scale structure of the universe. According to the Planck mission team, and based on the standard model of cosmology, the total mass–energy of the known universe contains 4.9% ordinary matter, 26.8% dark matter and 68.3% dark energy. Thus, dark matter is estimated to constitute 84.5% of the total matter in the universe, while dark energy plus dark matter constitute 95.1% of the total content of the universe. [6]

Cosmic microwave background

The cosmic microwave background (CMB) is the thermal radiation assumed to be left over from the "Big Bang" of cosmology. When the universe cooled enough, protons and electrons combined to form neutral atoms. These atoms could no longer absorb the thermal radiation, and so the universe became transparent instead of being an opaque fog. [7]

Thermal radiation

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation. When the temperature of the body is greater than absolute zero, interatomic collisions cause the kinetic energy of the atoms or molecules to change. This results in charge-acceleration and/or dipole oscillation which produces electromagnetic radiation, and the wide spectrum of radiation reflects the wide spectrum of energies and accelerations that occur even at a single temperature. [8]



Conclusions

The operational equivalence of coherence and entanglement will likely have a far-reaching impact on areas ranging from quantum information theory to more nascent fields such as quantum biology and nanoscale thermodynamics. In the future, the physicists plan to investigate whether coherence and entanglement might also be interconverted into a third resource—that of quantum discord, which, like entanglement, is another type of quantum correlation between two systems. [10]
The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]
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]
One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .
The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter. Since the dark matter not participating in the diffraction patterns, also cannot be part of quantum entanglement, because of this we haven't information about it, we conclude its existence from its gravitational effect only.

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