

# Mass Estimate for Elusive Neutrino

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*An international team of scientists has announced a breakthrough in its quest to measure the mass of the neutrino, one of the most abundant, yet elusive, elementary particles in our universe. [27]*

*In the quest to prove that matter can be produced without antimatter, the GERDA experiment at the Gran Sasso Underground Laboratory in Italy is looking for signs of neutrinoless double beta decay. [26]*

*The announcement was made during the CHARM 2018 international workshop in Novosibirsk in Russia: a charming moment for this doubly charmed particle. [25]*

*The group, in work published in Physical Review Letters, has now used powerful theoretical and computational tools to predict the existence of a "most strange" dibaryon, made up of two "Omega baryons" that contain three strange quarks each. [24]*  
*The nuclear physicists found that the proton's building blocks, the quarks, are subjected to a pressure of 100 decillion Pascal ( $10^{35}$ ) near the center of a proton, which is about 10 times greater than the pressure in the heart of a neutron star. [23]*

*In experimental campaigns using the OMEGA EP laser at the Laboratory for Laser Energetics (LLE) at the University of Rochester, Lawrence Livermore National Laboratory (LLNL), University of California San Diego (UCSD) and Massachusetts Institute of Technology (MIT) researchers took radiographs of the shock front, similar to the X-ray radiology in hospitals with protons instead of X-rays. [22]*

*Researchers generate proton beams using a combination of nanoparticles and laser light. [21]*

*Devices based on light, rather than electrons, could revolutionize the speed and security of our future computers. However, one of the major challenges in today's physics is the design of photonic devices, able to transport and switch light through circuits in a stable way. [20]*

*Researchers characterize the rotational jiggling of an optically levitated nanoparticle, showing how this motion could be cooled to its quantum ground state. [19]*

*Researchers have created quantum states of light whose noise level has been "squeezed" to a record low. [18]*

*An elliptical light beam in a nonlinear optical medium pumped by "twisted light" can rotate like an electron around a magnetic field. [17]*

*Physicists from Trinity College Dublin's School of Physics and the CRANN Institute, Trinity College, have discovered a new form of light, which will impact our understanding of the fundamental nature of light. [16]*

*Light from an optical fiber illuminates the metasurface, is scattered in four different directions, and the intensities are measured by the four detectors. From this measurement the state of polarization of light is detected. [15]*

*Converting a single photon from one color, or frequency, to another is an essential tool in quantum communication, which harnesses the subtle correlations between the subatomic properties of photons (particles of light) to securely store and transmit information. Scientists at the National Institute of Standards and Technology (NIST) have now developed a miniaturized version of a frequency converter, using technology similar to that used to make computer chips. [14]*

*Harnessing the power of the sun and creating light-harvesting or light-sensing devices requires a material that both absorbs light efficiently and converts the energy to highly mobile electrical current. Finding the ideal mix of properties in a single material is a challenge, so scientists have been experimenting with ways to combine different materials to create "hybrids" with enhanced features. [13]*

*Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological polariton, or “topolariton”: a hybrid half-light, half-matter quasiparticle that has special topological properties and might be used in devices to transport light in one direction. [12]*

*Solitons are localized wave disturbances that propagate without changing shape, a result of a nonlinear interaction that compensates for wave packet dispersion. Individual solitons may collide, but a defining feature is that they pass through one another and emerge from the collision unaltered in shape, amplitude, or velocity, but with a new trajectory reflecting a discontinuous jump.*

*Working with colleagues at the Harvard-MIT Center for Ultracold Atoms, a group led by Harvard Professor of Physics Mikhail Lukin and MIT Professor of Physics Vladan Vuletic have managed to coax photons into binding together to form molecules – a state of matter that, until recently, had been purely theoretical. The work is described in a September 25 paper in Nature.*

*New ideas for interactions and particles: This paper examines the possibility to origin the Spontaneously Broken Symmetries from the Planck Distribution Law. This way we get a Unification of the Strong, Electromagnetic, and Weak Interactions from the interference occurrences of oscillators. Understanding that the relativistic mass change is the result of the magnetic induction we arrive to the conclusion that the Gravitational Force is also*

*based on the electromagnetic forces, getting a Unified Relativistic Quantum Theory of all 4 Interactions.*

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### **KATRIN cuts the mass estimate for the elusive neutrino in half**

An international team of scientists has announced a breakthrough in its quest to measure the mass of the neutrino, one of the most abundant, yet elusive, elementary particles in our universe.

At the [2019 Topics in Astroparticle and Underground Physics](#) conference in Toyama, Japan, leaders from the KATRIN experiment reported Sept. 13 that the estimated range for the rest mass of the neutrino is no larger than 1 electron volt, or eV. These inaugural results obtained earlier this year by [the Karlsruhe Tritium Neutrino experiment](#)—or KATRIN—cut the mass range for the neutrino by more than half by lowering the upper limit of the neutrino's mass from 2 eV to 1 eV. The lower limit for the neutrino mass, 0.02 eV, was set by previous experiments by other groups.

"Knowing the mass of the neutrino will allow scientists to answer fundamental questions in cosmology, astrophysics and particle physics, such as how the universe evolved or what physics exists beyond the Standard Model," said Hamish Robertson, a KATRIN scientist and professor emeritus of physics at the University of Washington. "These findings by the KATRIN collaboration reduce the previous mass range for the neutrino by a factor of two, place more stringent criteria on what the neutrino's mass actually is, and provide a path forward to measure its value definitively."

The KATRIN experiment is based at the Karlsruhe Institute of Technology in Germany and involves researchers at 20 research institutions around the globe. In addition to the University of Washington, KATRIN member institutions in the United States are:

The University of North Carolina at Chapel Hill, led by professor of physics and astronomy John Wilkerson, a former UW faculty member

The Massachusetts Institute of Technology, led by professor of physics Joseph Formaggio

The Lawrence Berkeley National Laboratory, led by Nuclear Science Division deputy director Alan Poon

Carnegie Mellon University, led by assistant professor of physics Diana Parno

Case Western Reserve University, led by associate professor of physics Benjamin Monreal

Under Robertson and Wilkerson, the University of Washington became one of KATRIN's founding member institutions in 2001. Wilkerson later moved to the University of North Carolina at Chapel Hill. Formaggio and Parno began their involvement with KATRIN as UW researchers and later moved to their current institutions. In addition to Robertson, other current UW scientists working on the KATRIN experiment are research professor of physics Peter Doe, research associate professor of physics Sanshiro Enomoto and Menglei Sun, a postdoctoral researcher in the UW Center for Experimental Nuclear Physics and Astrophysics.

Neutrinos are abundant. They are one of the most common fundamental particles in our universe, second only to photons. Yet neutrinos are also elusive. They are neutral particles with no charge and they interact with other matter only through the aptly named "weak interaction," which means that opportunities to detect neutrinos and measure their mass are both rare and difficult.



The spectrometer for the KATRIN experiment, as it works its way through the German town of Eggenstein-Leopoldshafen in 2006 on its way to the nearby Karlsruhe Institute of Technology. Credit: Karlsruhe Institute of Technology

"If you filled the solar system with lead out to fifty times beyond the orbit of Pluto, about half of the neutrinos emitted by the sun would still leave the solar system without interacting with that lead," said Robertson.

Neutrinos are also mysterious particles that have already shaken up physics, cosmology and astrophysics. The Standard Model of particle physics had once predicted that neutrinos should have no mass. But by 2001, scientists had shown with two detectors, Super-Kamiokande and the Sudbury Neutrino Observatory, that they actually do have a nonzero mass—a breakthrough recognized in 2015 with the Nobel Prize in Physics. Neutrinos have mass, but how much?

"Solving the mass of the neutrino would lead us into a brave new world of creating a new Standard Model," said Doe.

The KATRIN discovery stems from direct, high-precision measurements of how a rare type of electron-neutrino pair share energy. This approach is the same as neutrino mass experiments from the 1990s and early 2000s in Mainz, Germany, and Troitsk, Russia, both of which set the previous upper limit of the mass at 2 eV. The heart of the KATRIN experiment is the source that generates electron-neutrino pairs: gaseous tritium, a highly radioactive isotope of hydrogen. As the tritium nucleus undergoes radioactive decay, it emits a pair of particles: one electron and one neutrino, both sharing 18,560 eV of energy.

KATRIN scientists cannot directly measure the neutrinos, but they can measure electrons, and try to calculate neutrino properties based on electron properties.



Most of the electron-neutrino pairs emitted by the tritium share their energy load equally. But in rare cases, the electron takes nearly all the energy—leaving only a tiny amount for the neutrino. Those rare pairs are what KATRIN scientists are after because—thanks to  $E = mc^2$ —scientists know that the miniscule amount of energy left for the neutrino must include its rest mass. If KATRIN can accurately measure the electron's energy, they can calculate the neutrino's energy and therefore its mass.

The tritium source generates about 25 billion electron-neutrino pairs each second, only a fraction of which are pairs where the electron takes nearly all the decay energy. The KATRIN facility in Karlsruhe uses a complex series of magnets to channel the electron away from the tritium source and toward an electrostatic spectrometer, which measures the energy of the electrons with high precision. An electric potential within the spectrometer creates an "energy gradient" that electrons must "climb" in order to pass through the spectrometer for detection. Adjusting the electric potential allows scientists to study the rare, high-energy electrons, which carry information concerning the neutrino mass.



In this 2010 image, members of the KATRIN experiment pose in front of the spectrometer after it was installed at the Karlsruhe Institute of Technology. Credit: Joachim Wolf/Karlsruhe Institute of Technology

U.S. institutions have made broad contributions to KATRIN, including providing the electron-detector system—the "eye" of KATRIN—which looks into the heart of the spectrometer, an instrument built at the UW. The University of North Carolina at Chapel Hill led the development of the detector's data acquisition system, the "brains" of KATRIN. MIT's contribution was the design and development of the simulation software used to model the response of KATRIN. The Lawrence Berkeley National Laboratory contributed to the creation of the physics analysis program and provided access to national computing facilities, and quick analysis was enabled by a suite of applications that originated at the UW. The Case Western Reserve University was responsible for the design of the electron gun, central to calibrating the KATRIN apparatus.

Carnegie Mellon University contributed primarily to analysis, with special attention to background and to fitting, and assisted in analysis coordination for the experiment.

With tritium data acquisition now underway, U.S. institutions are focused on analyzing these data to further improve our understanding of neutrino mass. These efforts may also reveal the existence of sterile [neutrinos](#), a possible candidate for the dark matter that, though accounting for 85% of the matter in the universe, remains undetected.

"KATRIN is not only a shining beacon of fundamental research and an outstandingly reliable high-tech instrument, but also a motor of international cooperation, which provides first-class training of young researchers," said KATRIN co-spokespersons Guido Drexlin of the Karlsruhe Institute of Technology and Christian Weinheimer of the University of Münster in a statement.

Now that KATRIN scientists have set a new upper limit for the [mass](#) of the neutrino, project scientists are working to narrow the range even further.

"Neutrinos are strange little particles," said Doe. "They're so ubiquitous, and there's so much we can learn once we determine this value."

The U.S. Department of Energy's Office of Nuclear Physics has funded the U.S. participation in the KATRIN experiment since 2007. [27]

## Major steps forward in understanding neutrino properties

In the quest to prove that matter can be produced without antimatter, the GERDA experiment at the Gran Sasso Underground Laboratory in Italy is looking for signs of neutrinoless double beta decay. The experiment has the greatest sensitivity worldwide for detecting the decay in question. To further improve the chances of success, a follow-up project, LEGEND, uses an even more refined decay experiment.

While the Standard Model of Particle Physics has remained mostly unchanged since its initial conception, experimental observations for neutrinos have forced the neutrino part of the theory to be reconsidered in its entirety.

Neutrino oscillation was the first observation inconsistent with the predictions, and proves that neutrinos have non-zero masses, a property that contradicts the Standard Model. In 2015, this discovery was rewarded with the Nobel Prize.

Additionally, there is the longstanding conjecture that neutrinos are so-called Majorana particles: Unlike all other constituents of matter, neutrinos might be their own antiparticles. This would also explain why there is so much more matter than antimatter in the universe.

The GERDA experiment is designed to scrutinize the Majorana hypothesis by searching for the neutrinoless double beta [decay](#) of the germanium isotope  $^{76}\text{Ge}$ : Two neutrons inside a  $^{76}\text{Ge}$  nucleus simultaneously transform into two protons with the emission of two electrons. This decay is forbidden in the Standard Model because the two antineutrinos—the balancing antimatter—are missing.



The Technical University of Munich (TUM) has been a key partner of the GERDA project (GERmanium Detector Array) for many years. Prof. Stefan Schönert, who heads the TUM research group, is the speaker of the new LEGEND project.



Credit: GERDA Collaboration

### ***The GERDA experiment achieves extreme levels of sensitivity***

GERDA is the first experiment to reach exceptionally low levels of background noise and has now surpassed the half-life sensitivity for decay of  $10^{26}$  years. In other words, GERDA proves that the process has a half-life of at least  $10^{26}$  years, or 10,000,000,000,000,000 times the age of the universe.

Physicists know that neutrinos are at least 100,000 times lighter than electrons, the next heaviest particles. Their exact mass, however, is still unknown, and is another important research topic.

In the standard interpretation, the half-life of the neutrinoless double beta decay is related to a special variant of the neutrino mass called the Majorana mass. Based on the new GERDA limit and those from other experiments, this mass must be at least 1 million times smaller than that of an electron, or in the terms of physicists, less than 0.07 to 0.16 eV/c<sup>2</sup>.

In particle physics masses are specified not in kilograms, but rather in accordance with Einstein's equation  $E=mc^2$ : electron volts [eV] divided by the speed of light squared. Electron volts are a measure of energy. This convention is used to circumvent unfathomably small units of mass: 1 eV/c<sup>2</sup> corresponds to  $1.8 \times 10^{-36}$  kilograms.

## ***Consistent with other experiments***

Additionally, other experiments limit the neutrino mass: The Planck mission provides a limit on another variant of the neutrino mass—the sum of the masses of all known neutrino types is less than 0.12 to 0.66 eV/c<sup>2</sup>.

The tritium decay experiment KATRIN at the Karlsruhe Institute of Technology (KIT) is set up to measure the neutrino mass with a sensitivity of about 0.2 eV/c<sup>2</sup> in coming years. These masses are not directly comparable, but they provide a cross-check on the paradigm that [neutrinos](#) are Majorana particles. So far, no discrepancy has been observed.

## ***From GERDA to LEGEND***

During the reported data collection period, GERDA operated detectors with a total mass of 35.6 kg of <sup>76</sup>Ge. Now, a newly formed international collaboration, LEGEND, will increase this [mass](#) to 200 kg of <sup>76</sup>Ge until 2021 and further reduce the background noise. The aim is to achieve a sensitivity of 10<sup>27</sup> years within the next five years. [26]

## **Long live the doubly charmed particle**

Finding a new particle is always a nice surprise, but measuring its characteristics is another story and just as important. Less than a year after announcing the discovery of the particle going by the snappy name of  $\Xi_{cc}^{++}$  ( $\Xi_{cc}^{++}$ ), this week the LHCb collaboration announced the first measurement of its lifetime. The announcement was made during the [CHARM 2018 international workshop](#) in Novosibirsk in Russia: a charming moment for this doubly charmed particle.

The  $\Xi_{cc}^{++}$  particle is composed of two charm quarks and one up quark, hence it is a member of the baryon family (particles composed of three quarks). The existence of the particle was predicted by the Standard Model, the theory which describes elementary particles and the forces that bind them together. LHCb's observation came last year after several years of research. Its mass was measured to be around 3621 MeV, almost four times that of the proton (the best-known baryon), thanks to its two [charm quarks](#).

The  $\Xi_{cc}^{++}$  particle is fleeting: it decays quickly into lighter particles. In fact it was through its decay into a  $\Lambda c^+$  baryon and three lighter mesons,  $K^-$ ,  $\pi^+$  and  $\pi^+$ , that it was discovered. Since then, LHCb physicists have been carrying on an analysis to determine its lifetime with a high level of precision. The value obtained is 0.256 picoseconds (0.000000000000256 seconds), with a small degree of uncertainty. Though very small in everyday life, such an amount of time is relatively large in the realm of subatomic particles. The measured value is within the range predicted by theoretical physicists on the basis of the Standard Model, namely between 0.20 and 1.05 picoseconds.

To achieve this precise result, LHCb physicists compared the measurement of the lifetime of the  $\Xi_{cc}^{++}$  with that of another particle whose lifetime is well-known. They based their measurements on the same sample of events that led to the discovery.

Measuring the lifetime of a particle is an important step in determining its characteristics. Thanks to the abundance of heavy quarks produced by the Large Hadron Collider (LHC) and the excellent precision of the

LHCb detector, physicists will now continue their detailed measurements of the properties of this charming particle. With these types of measurements, they are gaining a better understanding of the interactions that govern the behaviour of [particles](#) containing [heavy quarks](#). [25]

## Using the K computer, scientists predict exotic "di-Omega" particle

Based on complex simulations of quantum chromodynamics performed using the K computer, one of the most powerful computers in the world, the HAL QCD Collaboration, made up of scientists from the RIKEN Nishina Center for Accelerator-based Science and the RIKEN Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS) program, together with colleagues from a number of universities, have predicted a new type of "dibaryon"—a particle that contains six quarks instead of the usual three. Studying how these elements form could help scientists understand the interactions among elementary particles in extreme environments such as the interiors of neutron stars or the early universe moments after the Big Bang.

Particles known as "baryons"—principally protons and neutrons—are composed of three quarks bound tightly together, with their charge depending on the "color" of the quarks that make them up. A dibaryon is essentially a system with two baryons. There is one known dibaryon in nature—deuteron, a deuterium (or heavy-hydrogen) nucleus that contains a proton and a [neutron](#) that are very lightly bound. Scientists have long wondered whether there could be other types of dibaryons. Despite searches, no other dibaryon has been found.

The group, in work published in *Physical Review Letters*, has now used powerful theoretical and computational tools to predict the existence of a "most strange" dibaryon, made up of two "Omega baryons" that contain three strange quarks each. They named it "di-Omega". The group also suggested a way to look for these strange [particles](#) through experiments with heavy ion collisions planned in Europe and Japan.

The finding was made possible by a fortuitous combination of three elements: better methods for making QCD calculations, better simulation algorithms, and more powerful supercomputers.

The first essential element was a new theoretical framework called the "time-dependent HAL QCD method": It allows researchers to extract the force acting between baryons from the large volume of numerical data obtained using the K computer.

The second element was a new computational method, the unified contraction algorithm, which allows much more efficient calculation of a system with a large number of quarks.

The third [element](#) was the advent of powerful supercomputers. According to Shinya Gongyo from the RIKEN Nishina Center, "We were very lucky to have been able to use the K computer to perform the calculations. It allowed fast calculations with a huge number of variables. Still, it took almost three years for us to reach our conclusion on the di-Omega."

Discussing the future, Tetsuo Hatsuda from RIKEN iTHEMS says, "We believe that these special particles could be generated by the experiments using [heavy ion collisions](#) that are planned in Europe and in Japan, and we look forward to working with colleagues there to experimentally discover the first dibaryon system

outside of deuteron. This work could give us hints for understanding the interaction among strange baryons (called hyperons) and to understand how, under extreme conditions like those found in [neutron stars](#), normal matter can transition to what is called hyperonic matter—made up of protons, neutrons, and strange-[quark](#) particles called hyperons, and eventually to quark matter composed of up, down and strange quarks." [24]

## First measurement of subatomic particle's mechanical property reveals distribution of pressure inside proton

Inside every proton in every atom in the universe is a pressure cooker environment that surpasses the atom-crushing heart of a neutron star. That's according to the first measurement of a mechanical property of subatomic particles, the pressure distribution inside the proton, which was carried out by scientists at the Department of Energy's Thomas Jefferson National Accelerator Facility.

The nuclear physicists found that the [proton's](#) building blocks, the quarks, are subjected to a [pressure](#) of 100 decillion Pascal ( $10^{35}$ ) near the center of a proton, which is about 10 times greater than the pressure in the heart of a neutron star. The result was recently published in the journal *Nature*.

"We found an extremely high outward-directed pressure from the center of the proton, and a much lower and more extended inward-directed pressure near the proton's periphery," explains Volker Burkert, Jefferson Lab Hall B Leader and a co-author on the paper.

Burkert says that the distribution of pressure inside the proton is dictated by the [strong force](#), the force that binds three quarks together to make a proton.

"Our results also shed light on the distribution of the strong force inside the proton," he said. "We are providing a way of visualizing the magnitude and distribution of the strong force inside the proton. This opens up an entirely new direction in nuclear and particle physics that can be explored in the future."

Once thought impossible to obtain, this measurement is the result of a clever pairing of two theoretical frameworks with existing data.

First, there are the generalized parton distributions. GPDs allow researchers to produce a 3-D image of the proton's structure as probed by the electromagnetic force. The second are the gravitational form factors of the proton. These form factors describe what the mechanical structure of the proton would be if researchers could probe the proton via the [gravitational force](#).

The theorist who developed the concept of gravitational form factors in 1966, Heinz Pagels, famously observed in the paper detailing them that there was "very little hope of learning anything about the detailed mechanical structure of a particle, because of the extreme weakness of the gravitational interaction."

Recent theoretical work, however, has connected GPDs to the gravitational form factors, allowing the results from electromagnetic probes of protons to substitute for gravitational probes.

"This is the beauty of it. You have this map that you think you will never get," said Latifa Elouadrhiri, a Jefferson Lab staff scientist and co-author on the paper. "But here we are, filling it in with this electromagnetic probe."

The electromagnetic probe consists of beams of electrons produced by the Continuous Electron Beam Accelerator Facility, a DOE Office of Science User Facility. These electrons are directed into the nuclei of atoms, where they interact electromagnetically with the quarks inside protons via a process called deeply virtual Compton scattering.

In the DVCS process, an electron enters a proton and exchanges a virtual photon with a quark, transferring energy to the quark and proton. A short time later, the proton releases this energy by emitting another photon and continues on intact. This process is analogous to the calculations Pagels performed for how it would be possible to probe the proton gravitationally via a hypothetical beam of gravitons. The Jefferson Lab researchers were able to exploit a similarity between the well-known electromagnetic and hypothetical gravitational studies to get their result.

"There's a photon coming in and a photon coming out. And the pair of photons both are spin-1. That gives us the same information as exchanging one graviton particle with spin-2," says Francois-Xavier Girod, a Jefferson Lab staff scientist and co-author on the paper. "So now, one can basically do the same thing that we have done in electromagnetic processes—but relative to the gravitational form factors, which represent the [mechanical structure](#) of the proton."

The researchers say the next step is to apply the technique to even more precise data that will be available soon to reduce the uncertainties in the current analysis and begin working toward revealing other mechanical properties of the ubiquitous proton, such as the internal shear forces and the proton's mechanical radius. [23]

## Shock front probed by protons

A shock front is usually considered as a simple discontinuity in density or pressure. Yet in strongly shocked gases, the atoms are ionized into electrons and ions. The large difference in the electron pressure across the shock front can generate a strong electric field.

In experimental campaigns using the OMEGA EP laser at the Laboratory for Laser Energetics (LLE) at the University of Rochester, Lawrence Livermore National Laboratory (LLNL), University of California San Diego (UCSD) and Massachusetts Institute of Technology (MIT) researchers took radiographs of the shock front, similar to the X-ray radiology in hospitals with protons instead of X-rays.

Protons are charged particles that can be deflected by an electric field. Therefore, detecting the changes in their trajectories will provide information on the electric field. "Our proton probe is broadband," said Rui Hua, a graduate student at UCSD and the first author of the paper published in *Applied Physical Letters*. "Measuring energy-dependent deflections allows us to quantitatively study the electric potential and the potential width." The team also published a paper in *Review of Scientific Instruments* earlier this year to describe this platform.



The team observed an electric field of about 800 million volts per meter. "An analytical model agrees very well with our data," said Yuan Ping, LLNL co-author and the campaign lead. "So we don't have to rely on hydrodynamic codes to interpret the data."

The team plans to carry out more shots with higher-pressure shocks, and also in convergent geometry to simulate the conditions in the capsule implosion for ICF. "This is a perfect example of collaboration between the Lab and academia," said Farhat Beg, director of the Center for Energy Research at UCSD.

The team's research is available at Applied Physical Letters. [22]

## **Researchers generate proton beams using a combination of nanoparticles and laser light**

Light, when strongly concentrated, is enormously powerful. Now, a team of physicists led by Professor Jörg Schreiber from the Institute of Experimental Physics – Medical Physics, which is part of the Munich-Centre for Advanced Photonics (MAP), a Cluster of Excellence at LMU Munich, has used this energy source with explosive effect. The researchers focus high-power laser light onto beads of plastic just a few micrometers in size. The concentrated energy blows the nanoparticles apart, releasing radiation made up of positively charged atoms (protons). Such proton beams could be used in future for treating tumors, and in advanced imaging techniques. Their findings appear in the journal Physical Review E.

At Texas Petawatt Lasers in Austin, Texas, the LMU physicists concentrated laser light so strongly on plastic nanobeads that these essentially exploded. In the experiment, approximately one quadrillion billion photons (3 times  $10^{20}$  photons) were focused onto microspheres of about 500 nanometers in diameter. Each bead consists of about 50 billion carbon and hydrogen atoms and is held in suspension by the electromagnetic fields of a so-called "Paul trap", where the laser beam can irradiate them.

The laser radiation rips away some 15 per cent of the electrons bound in these atoms. The remaining, positively charged atomic nuclei are then violently repelled, and the nanospheres explode at speeds of around 10 per cent the speed of light. The radiation from the positively charged particles (protons) then spreads out in all directions.

This mode of production of proton beams with laser light promises to open up new opportunities for nuclear medicine – for example, in the fight against tumors. At present, proton beams are produced in conventional accelerators. In contrast, laser-generated proton beams open the door to the development of novel, perhaps even cheaper and more efficient, methods of treatment. The Munich-based team led by Jörg Schreiber has hitherto produced proton radiation using a diamondlike film, which is targeted by extremely strong laser light. The proton radiation thus emitted could then be directed onto the body of a patient.

The ability to produce radiation by the explosive disintegration of plastic nanobeads might even allow the nanoparticles to be placed inside a tumor, and be vaporized with laser light. Thus proton beams could be put to work in destroying tumors without causing damage to surrounding healthy tissue. [21]

## Towards stable propagation of light in nano-photonic fibers

Devices based on light, rather than electrons, could revolutionize the speed and security of our future computers. However, one of the major challenges in today's physics is the design of photonic devices, able to transport and switch light through circuits in a stable way. Sergej Flach, Director of the Center for Theoretical Physics of Complex Systems, within the Institute for Basic Science (IBS) and colleagues from the National Technical University of Athens and the University of Patras (Greece) have studied how to achieve a more stable propagation of light for future optical technologies. Their model was recently published in Scientific Reports.

Optical fibers can carry a large amount of information and are already used in many countries for communications via phone, internet and TV. However, when light travels long distances through these fibers, it suffers from losses and leakages, which could lead to a loss of information. In order to compensate for this problem, amplifiers are positioned at specific intervals to amplify the signal. For example, amplifiers are needed in submarine communications cables that allow the transfer of digital data between all continents (except for Antarctica). Researchers have tried to build fibers where the signal is stable along the pathway and does not need amplifiers, using the so-called "PT symmetry". P stands for parity reversal and T for time reversal.

The PT symmetry can be simplified with an example. Imagine a situation where two cars are traveling at the same speed at some instant in time. However, one car is speeding up and the other one is slowing down. Using parity reversal (P) we exchange one car for the other. Using time reversal (T) we go back in time. If you are in the car that is accelerating, you can jump to the car that is slowing down (P) and you also go back in time (T). As a result, you will end up with the same speed as the accelerating car. The cars are like light waves inside the optical fibers and the speed is a representation of the intensity of light. The jumping symbolizes of the transfer of light from one fiber to another, which happens when the light waves propagating in each fiber overlap partially with each other, through a phenomenon called tunneling.

The PT symmetry idea is that one can carefully balance the intensity of light inside the fibers and achieve a stable propagation. Researchers expected PT symmetry to be the solution to achieve stable propagation in all-optical devices (diodes, transistors, switches etc.). However, stable propagation is still a challenge because the PT symmetry conditions have to be balanced extremely carefully, and because the material of the fibers reacts and destroys the exact balance. In the example of the cars, in order to achieve perfect PT symmetry, you would need really identical cars and street conditions. Reality is of course much different.

The team led by IBS found that the stability of light propagation can be achieved by breaking the PT symmetry in a controlled way. In the example of the cars, you would have to choose two cars that are actually different (for example, one has a better engine than the other), but you choose the differences deliberately.

"You have the potential to realize a lot of the items of the wish-list of the PT symmetry, by breaking the PT symmetry. But you have to break it in the right way," explains Professor Flach. "Now we know how to tune the characteristics of the fiber couplers to achieve a long-lasting constant light propagation." [20]

## Synopsis: Twisting in Thin Air

Levitated nanoparticles can be used in ultrasensitive force measurements and fundamental tests of quantum physics. Unlike prior efforts that have focused on the translational vibrations of these nanoparticles, a new study considers the torsional motion. The researchers used polarized laser light to measure, for the first time, the twisting oscillations of oblong-shaped nanoparticles in a vacuum. The results suggest that this torsional motion can be cooled to zero oscillations (on average), corresponding to the torsional ground state.

For levitation experiments, focused laser beams create a trap that confines the translational motion of nanoparticles to back-and-forth oscillations at a specific frequency. Laser cooling can reduce these oscillations, but current techniques cannot reach the ground state. One solution is higher oscillation frequencies. In this case, the energy left after cooling is less than one quantum of oscillation, so the nanoparticle ends up in its ground state. However, making a higher-frequency optical trap would require higher laser power, which has the negative effect of heating the nanoparticles.

An alternative path is the use of a different oscillation mode. Tongcang Li of Purdue University, Indiana, and collaborators investigated the torsional motions of nanoparticles levitated with a linearly polarized laser. The oblong-shaped nanoparticles within the sample aligned themselves lengthwise along the laser's polarization axis. The researchers showed that these ellipsoids twist back and forth around this axis with a frequency of 1 MHz, a factor of 6 higher than that of the particles' translational vibrations. The team outlined a possible cooling method that could place nanoparticles in their torsional ground state. They also imagined the system as an ultrasensitive detector that could measure torques on single particles. [19]

## Researchers have created quantum states of light whose noise level has been “squeezed” to a record low

Squeezed quantum states of light can have better noise properties than those imposed by classical limits set by shot noise. Such states might help researchers boost the sensitivity of gravitationalwave (GW) detectors or design more practical quantum information schemes. A team of researchers at the Institute for Gravitational Physics at the Leibniz University of Hanover, Germany, has now demonstrated a method for squeezing noise to record low levels. The new approach—compatible with the laser interferometers used in GW detectors—may lead to technologies for upgrading LIGO and similar observatories.

Squeezed light is typically generated in nonlinear crystals, in which one pump photon produces two daughter photons. Because the two photons are generated in the same quantum process, they exhibit correlations that can be exploited to reduce noise in measuring setups. Quantum squeezing can, in principle, reduce noise to arbitrarily low levels. But in practice, photon losses and detector noise limit the maximum achievable squeezing. The previous record was demonstrated by the Hanover team, who used a scheme featuring amplitude fluctuations that were about a factor of 19 lower than those expected from classical noise (12.7 dB of squeezing).

In their new work, the researchers bested themselves by increasing this factor to 32 (15 dB of squeezing), using a light-squeezing scheme with low optical losses and minimal fluctuations in the

phase of the readout scheme. The squeezed states are obtained at 1064 nm, the laser wavelength feeding the interferometers of all current GW observatories.

This research is published in Physical Review Letters. [18]

## Liquid Light with a Whirl

An elliptical light beam in a nonlinear optical medium pumped by “twisted light” can rotate like an electron around a magnetic field.

Magnetism and rotation have a lot in common. The effect of a magnetic field on a moving charge, the Lorentz force, is formally equivalent to the fictitious force felt by a moving mass in a rotating reference frame, the Coriolis force. For this reason, atomic quantum gases under rotation can be used as quantum simulators of exotic magnetic phenomena for electrons, such as the fractional quantum Hall effect. But there is no direct equivalent of magnetism for photons, which are massless and chargeless. Now, Niclas Westerberg and co-workers at Heriot-Watt University, UK, have shown how to make synthetic magnetic fields for light. They developed a theory that predicts how a light beam in a nonlinear optical medium pumped by “twisted light” will rotate as it propagates, just as an electron will whirl around in a magnetic field. More than that, the light will expand as it goes, demonstrating fluid-like behavior. We can expect synthetic magnetism for light to bring big insights into magnetism in other systems, as well as some beautiful images.

The idea that light can behave like a fluid and, even more interestingly, a superfluid (a fluid with zero viscosity), goes back at least to the 1990s. The analogy comes about because Maxwell’s equations for nearly collimated light in a nonlinear medium look like the Schrödinger equation for a superfluid of matter, modified to include particle interactions. Fluids of light, or photon fluids, propagating in bulk nonlinear media show a range of fluid and superfluid behavior, such as free expansion and shock waves. In microcavities, fluids of light can be strongly coupled to matter, such as semiconductor electron-hole pairs, to make hybrid entities known as polariton condensates. These condensates can exhibit quantized vortices, which are characteristic of superfluidity. Despite these impressive advances, it has proven difficult to induce the strong bulk rotation required for phenomena such as the quantum Hall effect to show up in photon fluids, hence the need for synthetic magnetism.

The concept of synthetic magnetism is borrowed from ultracold atoms. With atoms, it is experimentally unfeasible to reach a regime of rapid rotation corresponding to a large magnetic field, not least because the traps that confine the atoms are unable to provide the centripetal force to stop them from flying out. Instead, it is possible to take advantage of the fact that atoms have multiple internal states. These can be used to generate geometric phases, as opposed to dynamic phases (which can be imposed by any forces, whatever the structure of the internal states may be). A geometric phase, otherwise known as a Berry phase, arises when a system’s internal states (for example, its spin) smoothly follow the variations of an external field, so that its phase depends on which path it takes between two external states (for example, two positions of the system), even if the paths have the same energy. In atomic systems, the variations of the external field in position are achieved with phase or amplitude structures of the electromagnetic field of laser light. These variations can be engineered to produce the rotational equivalent of the vector potential for a

magnetic field on a charged particle, inducing strong bulk rotation that shows up as many vortices in a superfluid Bose-Einstein condensate.

To produce a geometric phase in a fluid of light, Westerberg and colleagues considered light with two coupled internal states—a spinor photon fluid. They studied two types of nonlinear media, with second- and third-order optical nonlinearities, respectively. The second-order nonlinearity comes in the form of mixing of three fields in a birefringent crystal, in which one field, the pump light field, splits into two further fields with orthogonal polarizations, these being the two required internal states of the spinor fluid. Slow spatial variations of the strong pump field generate a synthetic vector potential that is equivalent to a magnetic field for electric charges or rotation for atoms.

The third-order optical nonlinearity occurs in a medium with a refractive index that depends on the intensity of light. The spinor photon fluid in this case consists of weak fluctuations around a strong light field that carries orbital angular momentum (colloquially known as twisted light). The two internal states of the fluid are distinguished by their differing orbital angular momentum. The resulting vector potential produces synthetic magnetism, much as with the second-order nonlinearity.

Coincidentally, for the medium with a second-order nonlinearity, Westerberg and co-workers also propose using twisted light.

The authors present numerical simulations for both types of nonlinearity. For the second-order nonlinear medium, they show that an elliptical light beam in a synthetic magnetic field rotates about its propagation axis and expands as it propagates (Fig 1). The expansion shows that the light is behaving as a fluid in rotation. For the third-order nonlinear medium there is a trapped vortex that causes the beam to rotate, which is akin to cyclotron motion of a charge in a magnetic field. Short of spinning the medium extremely rapidly [9], it is not obvious how one could otherwise make a beam continuously rotate as it propagates.

Westerberg and colleagues' work makes important connections between several disparate topics: nonlinear optics, atomic physics, geometric phases, and light with orbital angular momentum. Spinor photon fluids in themselves are a new development. The complete state of a photon fluid—its amplitude, phase, and polarization—can be mapped out; this is not possible for atoms or electrons. Some of the authors of the present study have recently experimentally driven photon fluids past obstacles in ways that are hard to achieve for atoms, and obtained evidence for superfluidity through the phase of the photon fluid [10]—evidence that cannot be obtained for electronic magnetism. Furthermore, they have also made photon fluids that have nonlocal interactions, via thermal effects. Generalizing synthetic magnetism to nonlocal fluids of light will enlighten us about magnetism and rotation in solid-state and atomic superfluids. Experimental implementation will surely follow hot on the heels of this proposal. [17]

## **Physicists discover a new form of light**

Physicists from Trinity College Dublin's School of Physics and the CRANN Institute, Trinity College, have discovered a new form of light, which will impact our understanding of the fundamental nature of light.



One of the measurable characteristics of a beam of light is known as angular momentum. Until now, it was thought that in all forms of light the angular momentum would be a multiple of Planck's constant (the physical constant that sets the scale of quantum effects).

Now, recent PhD graduate Kyle Ballantine and Professor Paul Eastham, both from Trinity College Dublin's School of Physics, along with Professor John Donegan from CRANN, have demonstrated a new form of light where the angular momentum of each photon (a particle of visible light) takes only half of this value. This difference, though small, is profound. These results were recently published in the online journal Science Advances.

Commenting on their work, Assistant Professor Paul Eastham said: "We're interested in finding out how we can change the way light behaves, and how that could be useful. What I think is so exciting about this result is that even this fundamental property of light, that physicists have always thought was fixed, can be changed."

Professor John Donegan said: "My research focuses on nanophotonics, which is the study of the behaviour of light on the nanometer scale. A beam of light is characterised by its colour or wavelength and a less familiar quantity known as angular momentum. Angular momentum measures how much something is rotating. For a beam of light, although travelling in a straight line it can also be rotating around its own axis. So when light from the mirror hits your eye in the morning, every photon twists your eye a little, one way or another."

"Our discovery will have real impacts for the study of light waves in areas such as secure optical communications."

Professor Stefano Sanvito, Director of CRANN, said: "The topic of light has always been one of interest to physicists, while also being documented as one of the areas of physics that is best understood. This discovery is a breakthrough for the world of physics and science alike. I am delighted to once again see CRANN and Physics in Trinity producing fundamental scientific research that challenges our understanding of light."

To make this discovery, the team involved used an effect discovered in the same institution almost 200 years before. In the 1830s, mathematician William Rowan Hamilton and physicist Humphrey Lloyd found that, upon passing through certain crystals, a ray of light became a hollow cylinder. The team used this phenomenon to generate beams of light with a screw-like structure.

Analyzing these beams within the theory of quantum mechanics they predicted that the angular momentum of the photon would be half-integer, and devised an experiment to test their prediction. Using a specially constructed device they were able to measure the flow of angular momentum in a beam of light. They were also able, for the first time, to measure the variations in this flow caused by quantum effects. The experiments revealed a tiny shift, one-half of Planck's constant, in the angular momentum of each photon.

Theoretical physicists since the 1980s have speculated how quantum mechanics works for particles that are free to move in only two of the three dimensions of space. They discovered that this would enable strange new possibilities, including particles whose quantum numbers were fractions of those expected. This work shows, for the first time, that these speculations can be realised with light. [16]

## Novel metasurface revolutionizes ubiquitous scientific tool

Light from an optical fiber illuminates the metasurface, is scattered in four different directions, and the intensities are measured by the four detectors. From this measurement the state of polarization of light is detected.

What do astrophysics, telecommunications and pharmacology have in common? Each of these fields relies on polarimeters—instruments that detect the direction of the oscillation of electromagnetic waves, otherwise known as the polarization of light.

Even though the human eye isn't particularly sensitive to polarization, it is a fundamental property of light. When light is reflected or scattered off an object, its polarization changes and measuring that change reveals a lot of information. Astrophysicists, for example, use polarization measurements to analyze the surface of distant, or to map the giant magnetic fields spanning our galaxy. Drug manufacturers use the polarization of scattered light to determine the chirality and concentration of drug molecules. In telecommunications, polarization is used to carry information through the vast network of fiber optic cables. From medical diagnostics to high-tech manufacturing to the food industry, measuring polarization reveals critical data.

Scientists rely on polarimeters to make these measurements. While ubiquitous, many polarimeters currently in use are slow, bulky and expensive.

Now, researchers at the Harvard John A. Paulson School of Engineering and Applied Sciences and Innovation Center Iceland have built a polarimeter on a microchip, revolutionizing the design of this widely used scientific tool.

"We have taken an instrument that is can reach the size of a lab bench and shrunk it down to the size of a chip," said Federico Capasso, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering, who led the research. "Having a microchip polarimeter will make polarization measurements available for the first time to a much broader range of applications, including in energy-efficient, portable devices."

"Taking advantage of integrated circuit technology and nanophotonics, the new device promises high-performance polarization measurements at a fraction of the cost and size," said J. P. Balthasar Mueller, a graduate student in the Capasso lab and first author of the paper.

The device is described in the journal *Optica*. Harvard's Office of Technology Development has filed a patent application and is actively exploring commercial opportunities for the technology.

Capasso's team was able to drastically reduce the complexity and size of polarimeters by building a two-dimensional metasurface—a nanoscale structure that interacts with light. The metasurface is covered with a thin array of metallic antennas, smaller than a wavelength of light, embedded in a polymer film. As light propagates down an optical fiber and illuminates the array, a small amount scatters in four directions. Four detectors measure the intensity of the scattered light and combine to give the state of polarization in real time.

"One advantage of this technique is that the polarization measurement leaves the signal mostly intact," said Mueller. "This is crucial for many uses of polarimeters, especially in optical telecommunications, where measurements must be made without disturbing the data stream."

In telecommunications, optical signals propagating through fibers will change their polarization in random ways. New integrated photonic chips in fiber optic cables are extremely sensitive to polarization, and if light reaches a chip with the wrong polarization, it can cause a loss of signal.

"The design of the antenna array make it robust and insensitive to the inaccuracies in the fabrication process, which is ideal for large scale manufacturing," said Kristjan Leosson, senior researcher and division manager at the Innovation Center and coauthor of the paper.

Leosson's team in Iceland is currently working on incorporating the metasurface design from the Capasso group into a prototype polarimeter instrument.

Chip-based polarimeters could for the first time provide comprehensive and real-time polarization monitoring, which could boost network performance and security and help providers keep up with the exploding demand for bandwidth.

"This device performs as well as any state-of-the-art polarimeter on the market but is considerably smaller," said Capasso. "A portable, compact polarimeter could become an important tool for not only the telecommunications industry but also in drug manufacturing, medical imaging, chemistry, astronomy, you name it. The applications are endless." [15]

### **New nanodevice shifts light's color at single-photon level**

Converting a single photon from one color, or frequency, to another is an essential tool in quantum communication, which harnesses the subtle correlations between the subatomic properties of photons (particles of light) to securely store and transmit information. Scientists at the National Institute of Standards and Technology (NIST) have now developed a miniaturized version of a frequency converter, using technology similar to that used to make computer chips.

The tiny device, which promises to help improve the security and increase the distance over which next-generation quantum communication systems operate, can be tailored for a wide variety of uses, enables easy integration with other information-processing elements and can be mass produced.

The new nanoscale optical frequency converter efficiently converts photons from one frequency to the other while consuming only a small amount of power and adding a very low level of noise, namely background light not associated with the incoming signal.

Frequency converters are essential for addressing two problems. The frequencies at which quantum systems optimally generate and store information are typically much higher than the frequencies required to transmit that information over kilometer-scale distances in optical fibers. Converting the photons between these frequencies requires a shift of hundreds of terahertz (one terahertz is a trillion wave cycles per second).

A much smaller, but still critical, frequency mismatch arises when two quantum systems that are intended to be identical have small variations in shape and composition. These variations cause the systems to generate photons that differ slightly in frequency instead of being exact replicas, which the quantum communication network may require.

The new photon frequency converter, an example of nanophotonic engineering, addresses both issues, Qing Li, Marcelo Davanço and Kartik Srinivasan write in Nature Photonics. The key component of the chip-integrated device is a tiny ring-shaped resonator, about 80 micrometers in diameter (slightly less than the width of a human hair) and a few tenths of a micrometer in thickness. The shape and dimensions of the ring, which is made of silicon nitride, are chosen to enhance the inherent properties of the material in converting light from one frequency to another. The ring resonator is driven by two pump lasers, each operating at a separate frequency. In a scheme known as four-wave-mixing Bragg scattering, a photon entering the ring is shifted in frequency by an amount equal to the difference in frequencies of the two pump lasers.

Like cycling around a racetrack, incoming light circulates around the resonator hundreds of times before exiting, greatly enhancing the device's ability to shift the photon's frequency at low power and with low background noise. Rather than using a few watts of power, as typical in previous experiments, the system consumes only about a hundredth of that amount. Importantly, the added amount of noise is low enough for future experiments using single-photon sources.

While other technologies have been applied to frequency conversion, "nanophotonics has the benefit of potentially enabling the devices to be much smaller, easier to customize, lower power, and compatible with batch fabrication technology," said Srinivasan. "Our work is a first demonstration of a nanophotonic technology suitable for this demanding task of quantum frequency conversion." [14]

## **Quantum dots enhance light-to-current conversion in layered semiconductors**

Harnessing the power of the sun and creating light-harvesting or light-sensing devices requires a material that both absorbs light efficiently and converts the energy to highly mobile electrical current. Finding the ideal mix of properties in a single material is a challenge, so scientists have been experimenting with ways to combine different materials to create "hybrids" with enhanced features.

In two just-published papers, scientists from the U.S. Department of Energy's Brookhaven National Laboratory, Stony Brook University, and the University of Nebraska describe one such approach that combines the excellent light-harvesting properties of quantum dots with the tunable electrical conductivity of a layered tin disulfide semiconductor. The hybrid material exhibited enhanced light-harvesting properties through the absorption of light by the quantum dots and their energy transfer to tin disulfide, both in laboratory tests and when incorporated into electronic devices. The research paves the way for using these materials in optoelectronic applications such as energy-harvesting photovoltaics, light sensors, and light emitting diodes (LEDs).

According to Mircea Cotlet, the physical chemist who led this work at Brookhaven Lab's Center for Functional Nanomaterials (CFN), a DOE Office of Science User Facility, "Two-dimensional metal dichalcogenides like tin disulfide have some promising properties for solar energy conversion and photodetector applications, including a high surface-to-volume aspect ratio. But no semiconducting material has it all. These materials are very thin and they are poor light absorbers.

So we were trying to mix them with other nanomaterials like light-absorbing quantum dots to improve their performance through energy transfer."

One paper, just published in the journal ACS Nano, describes a fundamental study of the hybrid quantum dot/tin disulfide material by itself. The work analyzes how light excites the quantum dots (made of a cadmium selenide core surrounded by a zinc sulfide shell), which then transfer the absorbed energy to layers of nearby tin disulfide.

"We have come up with an interesting approach to discriminate energy transfer from charge transfer, two common types of interactions promoted by light in such hybrids," said Prahlad Routh, a graduate student from Stony Brook University working with Cotlet and co-first author of the ACS Nano paper. "We do this using single nanocrystal spectroscopy to look at how individual quantum dots blink when interacting with sheet-like tin disulfide. This straightforward method can assess whether components in such semiconducting hybrids interact either by energy or by charge transfer."

The researchers found that the rate for non-radiative energy transfer from individual quantum dots to tin disulfide increases with an increasing number of tin disulfide layers. But performance in laboratory tests isn't enough to prove the merits of potential new materials. So the scientists incorporated the hybrid material into an electronic device, a photo-field-effect-transistor, a type of photon detector commonly used for light sensing applications.

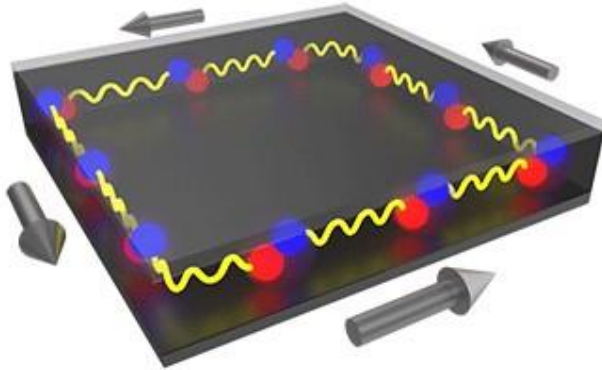
As described in a paper published online March 24 in Applied Physics Letters, the hybrid material dramatically enhanced the performance of the photo-field-effect transistors—resulting in a photocurrent response (conversion of light to electric current) that was 500 percent better than transistors made with the tin disulfide material alone.

"This kind of energy transfer is a key process that enables photosynthesis in nature," said ChangYong Nam, a materials scientist at Center for Functional Nanomaterials and co-corresponding author of the APL paper. "Researchers have been trying to emulate this principle in light-harvesting electrical devices, but it has been difficult particularly for new material systems such as the tin disulfide we studied. Our device demonstrates the performance benefits realized by using both energy transfer processes and new low-dimensional materials."

Cotlet concludes, "The idea of 'doping' two-dimensional layered materials with quantum dots to enhance their light absorbing properties shows promise for designing better solar cells and photodetectors." [13]



## Quasiparticles dubbed topological polaritons make their debut in the theoretical world



Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological polariton, or “topolariton”: a hybrid half-light, half-matter quasiparticle that has special topological properties and might be used in devices to transport light in one direction.

The proposed topolaritons arise from the strong coupling of a photon and an exciton, a bound state of an electron and a hole. Their topology can be thought of as knots in their gapped energy-band structure. At the edge of the systems in which topolaritons emerge, these knots unwind and allow the topolaritons to propagate in a single direction without back-reflection. In other words, the topolaritons cannot make U-turns. Back-reflection is a known source of detrimental feedback and loss in photonic devices. The topolaritons’ immunity to it may thus be exploited to build devices with increased performance.

The researchers describe a scheme to generate topolaritons that may be feasible to implement in common systems—such as semiconductor structures or atomically thin layers of compounds known as transition-metal dichalcogenides—embedded in photonic waveguides or microcavities. Previous approaches to make similar one-way photonic channels have mostly hinged on effects that are only applicable at microwave frequencies. Refael and co-workers’ proposal offers an avenue to make such “one-way photonic roads” in the optical regime, which despite progress has remained a challenging pursuit. [12]

### **'Matter waves' move through one another but never share space**

Physicist Randy Hulet and colleagues observed a strange disappearing act during collisions between forms of Bose Einstein condensates called solitons. In some cases, the colliding clumps of matter appear to keep their distance even as they pass through each other. How can two clumps of matter pass through each other without sharing space? Physicists have documented a strange disappearing act by colliding Bose Einstein condensates that appear to keep their distance even as they pass through one another.

BECs are clumps of a few hundred thousand lithium atoms that are cooled to within one-millionth of a degree above absolute zero, a temperature so cold that the atoms march in lockstep and act

as a single "matter wave." Solitons are waves that do not diminish, flatten out or change shape as they move through space. To form solitons, Hulet's team coaxed the BECs into a configuration where the attractive forces between lithium atoms perfectly balance the quantum pressure that tends to spread them out.

The researchers expected to observe the property that a pair of colliding solitons would pass through one another without slowing down or changing shape. However, they found that in certain collisions, the solitons approached one another, maintained a minimum gap between themselves, and then appeared to bounce away from the collision.

Hulet's team specializes in experiments on BECs and other ultracold matter. They use lasers to both trap and cool clouds of lithium gas to temperatures that are so cold that the matter's behavior is dictated by fundamental forces of nature that aren't observable at higher temperatures.

To create solitons, Hulet and postdoctoral research associate Jason Nguyen, the study's lead author, balanced the forces of attraction and repulsion in the BECs.

Cameras captured images of the tiny BECs throughout the process. In the images, two solitons oscillate back and forth like pendulums swinging in opposite directions. Hulet's team, which also included graduate student De Luo and former postdoctoral researcher Paul Dyke, documented thousands of head-on collisions between soliton pairs and noticed a strange gap in some, but not all, of the experiments.

Many of the events that Hulet's team measures occur in one-thousandth of a second or less. To confirm that the "disappearing act" wasn't causing a miniscule interaction between the soliton pairs -- an interaction that might cause them to slowly dissipate over time -- Hulet's team tracked one of the experiments for almost a full second.

The data showed the solitons oscillating back and fourth, winking in and out of view each time they crossed, without any measurable effect.

"This is great example of a case where experiments on ultracold matter can yield a fundamental new insight," Hulet said. "The phase-dependent effects had been seen in optical experiments, but there has been a misunderstanding about the interpretation of those observations." [11]

## **Photonic molecules**

Working with colleagues at the Harvard-MIT Center for Ultracold Atoms, a group led by Harvard Professor of Physics Mikhail Lukin and MIT Professor of Physics Vladan Vuletic have managed to coax photons into binding together to form molecules – a state of matter that, until recently, had been purely theoretical. The work is described in a September 25 paper in Nature.

The discovery, Lukin said, runs contrary to decades of accepted wisdom about the nature of light. Photons have long been described as massless particles which don't interact with each other – shine two laser beams at each other, he said, and they simply pass through one another.

"Photonic molecules," however, behave less like traditional lasers and more like something you might find in science fiction – the light saber.

"Most of the properties of light we know about originate from the fact that photons are massless, and that they do not interact with each other," Lukin said. "What we have done is create a special type of medium in which photons interact with each other so strongly that they begin to act as though they have mass, and they bind together to form molecules. This type of photonic bound state has been discussed theoretically for quite a while, but until now it hadn't been observed. [9]

## The Electromagnetic Interaction

This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. 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. [2]

## Asymmetry in the interference occurrences of oscillators

The asymmetrical configurations are stable objects of the real physical world, because they cannot annihilate. One of the most obvious asymmetry is the proton – electron mass rate  $M_p = 1840 M_e$  while they have equal charge. We explain this fact by the strong interaction of the proton, but how remember it his strong interaction ability for example in the H – atom where are only electromagnetic interactions among proton and electron.

This gives us the idea to origin the mass of proton from the electromagnetic interactions by the way interference occurrences of oscillators. The uncertainty relation of Heisenberg makes sure that the particles are oscillating.

The resultant intensity due to n equally spaced oscillators, all of equal amplitude but different from one another in phase, either because they are driven differently in phase or because we are looking at them an angle such that there is a difference in time delay:

$$(1) \quad I = I_0 \sin^2 n \varphi/2 / \sin^2 \varphi/2$$

If  $\varphi$  is infinitesimal so that  $\sin \varphi = \varphi$  than

$$(2) \quad I = n^2 I_0$$

This gives us the idea of

$$(3) \quad M_p = n^2 M_e$$

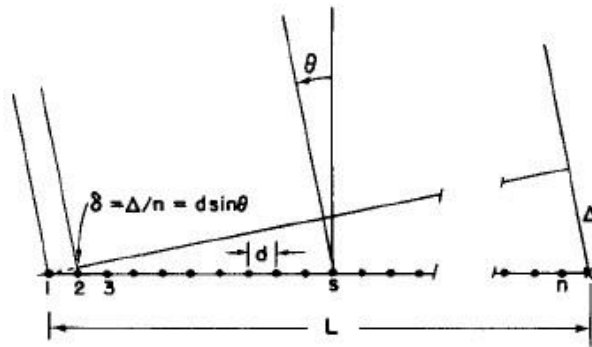


Fig. 30-3. A linear array of  $n$  equal oscillators, driven with phases  $\alpha_s = s\alpha$ .

Figure 1.) A linear array of  $n$  equal oscillators

There is an important feature about formula (1) which is that if the angle  $\varphi$  is increased by the multiple of  $2\pi$  it makes no difference to the formula.

So

$$(4) \quad d \sin \theta = m \lambda \text{ and we get } m\text{-order beam if } \lambda \text{ less than } d. [6]$$

If  $d$  less than  $\lambda$  we get only zero-order one centered at  $\theta = 0$ . Of course, there is also a beam in the opposite direction. The right choices of  $d$  and  $\lambda$  we can ensure the conservation of charge.

For example

$$(5) \quad 2(m+1) = n$$

Where  $2(m+1) = N_p$  number of protons and  $n = N_e$  number of electrons.

In this way we can see the  $H_2$  molecules so that  $2n$  electrons of  $n$  radiate to  $4(m+1)$  protons, because  $d_e > \lambda_e$  for electrons, while the two protons of one  $H_2$  molecule radiate to two electrons of them, because of  $d_e < \lambda_e$  for this two protons.

To support this idea we can turn to the Planck distribution law, that is equal with the Bose – Einstein statistics.

## Spontaneously broken symmetry in the Planck distribution law

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms molecules, crystals, dark matter and energy.

Max Planck found for the black body radiation

As a function of wavelength ( $\lambda$ ), Planck's law is written as:

$$B_{\lambda}(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

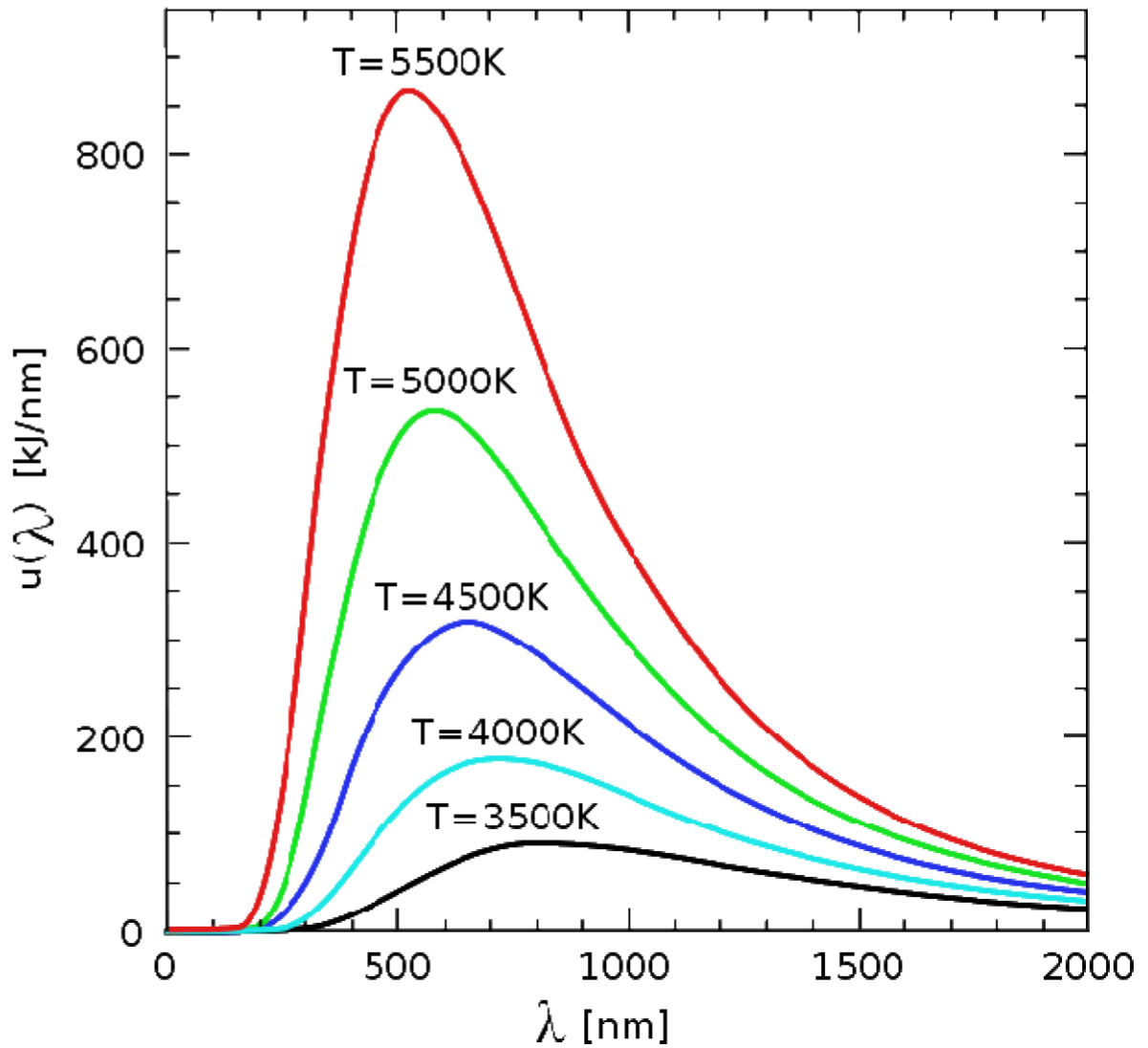


Figure 2. The distribution law for different T temperatures

We see there are two different  $\lambda_1$  and  $\lambda_2$  for each T and intensity, so we can find between them a d so that  $\lambda_1 < d < \lambda_2$ .

We have many possibilities for such asymmetrical reflections, so we have many stable oscillator configurations for any T temperature with equal exchange of intensity by radiation. All of these configurations can exist together. At the  $\lambda_{\max}$  is the annihilation point where the configurations are symmetrical. The  $\lambda_{\max}$  is changing by the Wien's displacement law in many textbooks.

$$(7) \quad \lambda_{\max} = \frac{b}{T}$$

where  $\lambda_{\max}$  is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to  $2.8977685(51) \times 10^{-3} \text{ m} \cdot \text{K}$  (2002 CODATA recommended value).



By the changing of T the asymmetrical configurations are changing too.

## The structure of the proton

We must move to the higher T temperature if we want look into the nucleus or nucleon arrive to  $d < 10^{-13}$  cm. If an electron with  $\lambda_e < d$  move across the proton then by (5)  $2(m+1) = n$  with  $m = 0$  we get  $n = 2$  so we need two particles with negative and two particles with positive charges. If the proton can fraction to three parts, two with positive and one with negative charges, then the reflection of oscillators are right. Because this very strange reflection where one part of the proton with the electron together on the same side of the reflection, the all parts of the proton must be quasi lepton so  $d > \lambda_q$ . One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order  $1/3$  e charge to each coordinates and  $2/3$  e charge to one plane oscillation, because the charge is scalar. In this way the proton has two  $+2/3$  e plane oscillation and one linear oscillation with  $-1/3$  e charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. The flavors of quarks are the possible oscillations differently by energy and if they are plane or linear oscillations. We know there is no possible reflecting two oscillations to each other which are completely orthogonal, so the quarks never can be free, however there is an asymptotic freedom while their energy are increasing to turn them to the orthogonally. If they will be completely orthogonal then they lose this reflection and take new partners from the vacuum. Keeping the symmetry of the vacuum the new oscillations are keeping all the conservation laws, like charge, number of baryons and leptons. The all features of gluons are coming from this model. The mathematics of reflecting oscillators show Fermi statistics.

Important to mention that in the Deuteron there are 3 quarks of  $+2/3$  and  $-1/3$  charge, that is three u and d quarks making the complete symmetry and because this its high stability.

The Pauli Exclusion Principle says that the diffraction points are exclusive!

## The Strong Interaction

### ***Confinement and Asymptotic Freedom***

For any theory to provide a successful description of strong interactions it should simultaneously exhibit the phenomena of confinement at large distances and asymptotic freedom at short distances. Lattice calculations support the hypothesis that for non-abelian gauge theories the two domains are analytically connected, and confinement and asymptotic freedom coexist. Similarly, one way to show that QCD is the correct theory of strong interactions is that the coupling extracted at various scales (using experimental data or lattice simulations) is unique in the sense that its variation with scale is given by the renormalization group. [4]

Lattice QCD gives the same results as the diffraction theory of the electromagnetic oscillators, which is the explanation of the strong force and the quark confinement. [1]

## 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.

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  $1/2$  spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with  $1/2$  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  $\frac{1}{2}$  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 than 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. [5]

## Fermions and Bosons

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

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several

proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

## The fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin:  $1/2 \hbar = \Delta x \Delta p$  or  $1/2 \hbar = \Delta t \Delta E$ , that is the value of the basic energy status.

What are the consequences of this in the weak interaction and how possible that the neutrinos' velocity greater than the speed of light?

The neutrino is the one and only particle doesn't participate in the electromagnetic interactions so we cannot expect that the velocity of the electromagnetic wave will give it any kind of limit.

The neutrino is a  $1/2$  spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with  $1/2$  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 source of the Maxwell equations

The electrons are accelerating also in a static electric current because of the electric force, caused by the potential difference. The magnetic field is the result of this acceleration, as you can see in [2].

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

Also an interesting question, how the changing magnetic field creates a negative electric field? The answer also the accelerating electrons will give. When the magnetic field is increasing in time by increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change. In this way

we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.

The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.

There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by weak interaction and can be understood by the Feynman graphs.

Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because 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 greatest proton mass.

## **The Special Relativity**

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed. [8]

## **The Heisenberg Uncertainty Principle**

Moving faster needs stronger acceleration reducing the  $\Delta x$  and raising the  $\Delta p$ . It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass ratio since the  $\Delta x$  is much less requiring bigger  $\Delta p$  in the case of the proton, which is partly the result of a bigger mass  $m_p$  because of the higher electromagnetic induction of the bigger frequency (impulse).

## The Gravitational force

The changing magnetic field of the changing current causes electromagnetic mass change by the negative electric field caused by the changing acceleration of the electric charge.

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 Big 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 ratio  $M_p = 1840 M_e$ . 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. [1]

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 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]

## 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 Casimir effect

The Casimir effect is related to the Zero-point energy, which is fundamentally related to the Heisenberg uncertainty relation. The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin:  $1/2 h = dx dp$  or  $1/2 h = dt dE$ , that is the value of the basic energy status.

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light. 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 is not a point like particle, but has a real

charge distribution.

Electric charge and electromagnetic waves are two sides of the same thing; the electric charge is the diffraction center of the electromagnetic waves, quantified by the Planck constant  $h$ .

## The Fine structure constant

The Planck constant was first described as the proportionality constant between the energy ( $E$ ) of a photon and the frequency ( $\nu$ ) of its associated electromagnetic wave. This relation between the energy and frequency is called the **Planck relation** or the **Planck–Einstein equation**:

$$E = h\nu .$$

Since the frequency  $\nu$ , wavelength  $\lambda$ , and speed of light  $c$  are related by  $\lambda\nu = c$ , the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda} .$$

Since this is the source of Planck constant, the electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass ratio is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law, described in my diffraction theory.

## Path integral formulation of Quantum Mechanics

The path integral formulation of quantum mechanics is a description of quantum theory which generalizes the action principle of classical mechanics. It replaces the classical notion of a single, unique trajectory for a system with a sum, or functional integral, over an infinity of possible trajectories to compute a quantum amplitude. [7]

It shows that the particles are diffraction patterns of the electromagnetic waves.

## Conclusions

The proposed topolaritons arise from the strong coupling of a photon and an exciton, a bound state of an electron and a hole. Their topology can be thought of as knots in their gapped energy-band structure. At the edge of the systems in which topolaritons emerge, these knots unwind and allow the topolaritons to propagate in a single direction without back-reflection. In other words, the topolaritons cannot make U-turns. Back-reflection is a known source of detrimental feedback and loss in photonic devices. The topolaritons' immunity to it may thus be exploited to build devices with increased performance. [12]

Solitons are localized wave disturbances that propagate without changing shape, a result of a nonlinear interaction that compensates for wave packet dispersion. Individual solitons may collide, but a defining feature is that they pass through one another and emerge from the collision unaltered in shape, amplitude, or velocity, but with a new trajectory reflecting a discontinuous jump. This remarkable property is mathematically a consequence of the underlying integrability of the onedimensional (1D) equations, such as the nonlinear Schrödinger equation, that describe solitons in a variety of wave contexts, including matter waves<sup>1, 2</sup>. Here we explore the nature of soliton collisions using Bose–Einstein condensates of atoms with attractive interactions confined to a quasi-1D waveguide. Using real-time imaging, we show that a collision between solitons is a complex event

that differs markedly depending on the relative phase between the solitons. By controlling the strength of the nonlinearity we shed light on these fundamental features of soliton collisional dynamics, and explore the implications of collisions in the proximity of the crossover between one and three dimensions where the loss of integrability may precipitate catastrophic collapse. [10]

"It's a photonic interaction that's mediated by the atomic interaction," Lukin said. "That makes these two photons behave like a molecule, and when they exit the medium they're much more likely to do so together than as single photons." To build a quantum computer, he explained, researchers need to build a system that can preserve quantum information, and process it using quantum logic operations. The challenge, however, is that quantum logic requires interactions between individual quanta so that quantum systems can be switched to perform information processing. [9]

The magnetic induction creates a negative electric field, causing an electromagnetic inertia responsible for the relativistic mass change; it is the mysterious Higgs Field giving mass to the particles. The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass ratio by the diffraction patterns. The accelerating charges 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 Relativistic Quantum Theories. The self-maintained electric potential of the accelerating charges equivalent with the General Relativity space-time curvature, and since it is true on the quantum level also, gives the base of the Quantum Gravity. The electric currents causing self-maintaining electric potential is the source of the special and general relativistic effects. The Higgs Field is the result of the electromagnetic induction. The Graviton is two photons together.

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