Forces Between Atoms

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New research shows that a scanning-tunneling microscope (STM), used to study changes in the shape of a single molecule at the atomic scale, impacts the ability of that molecule to make these changes. [26]

Physicists are getting a little bit closer to answering one of the oldest and most basic questions of quantum theory: does the quantum state represent reality or just our knowledge of reality? [25]

A team of researchers led by LMU physics professor Immanuel Bloch has experimentally realized an exotic quantum system which is robust to mixing by periodic forces. [24]

A group of scientists led by Johannes Fink from the Institute of Science and Technology Austria (IST Austria) reported the first experimental observation of a first-order phase transition in a dissipative quantum system. [23]

ORNL researchers have discovered a new type of quantum critical point, a new way in which materials change from one state of matter to another. [22]

New research conducted at the University of Chicago has confirmed a decades-old theory describing the dynamics of continuous phase transitions. [21]

No matter whether it is acoustic waves, quantum matter waves or optical waves of a laser—all kinds of waves can be in different states of oscillation, corresponding to different frequencies. Calculating these frequencies is part of the tools of the trade in theoretical physics. Recently, however, a special class *of systems has caught the attention of the scientific community, forcing physicists to abandon well-established rules. [20]*

Until quite recently, creating a hologram of a single photon was believed to be impossible due to fundamental laws of physics. However, scientists at the Faculty of Physics, University of Warsaw, have successfully applied concepts of classical holography to the world of quantum phenomena. A new measurement technique has enabled them to register the first-ever hologram of a single light particle, thereby shedding new light on the foundations of quantum mechanics. [19]

A combined team of researchers from Columbia University in the U.S. and the University of Warsaw in Poland has found that there appear to be flaws in traditional theory that describe how photodissociation works. [18]

Ultra-peripheral collisions of lead nuclei at the LHC accelerator can lead to elastic collisions of photons with photons. [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 polarition, 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.

Author: George Rajna

Controlling forces between atoms, molecules, promising for '2-D hyperbolic' materials

A new approach to control forces and interactions between atoms and molecules, such as those employed by geckos to climb vertical surfaces, could bring advances in new materials for developing quantum light sources.

"Closely spaced atoms and molecules in our environment are constantly interacting, attracting and repelling each other," said Zubin Jacob, an assistant professor of electrical and computer engineering at Purdue University. "Such interactions ultimately enable a myriad of phenomena, such as the sticky pads on gecko feet, as well as photosynthesis."

Typically, these interactions occur when atoms and molecules are between 1 to 10 nanometers apart, or roughly 1/10,000th the width of a human hair.

"These include Van der Waals forces that take place between atoms and molecules only when they are very close together. The fact that they always require extremely short separation distances makes them difficult to control. This poses a major obstacle to exploit them for practical applications," he said.

For brief periods of time atoms are said to possess "fluctuating dipoles" because their positive and negative charges are momentarily separated. The dipoles from numerous atoms and molecules sometimes interact with each other, and these dipole-dipole interactions are the basis for Van der Waals and other forces between the closely-spaced atoms and molecules.

The researchers have demonstrated that these dipole-dipole interactions are fundamentally altered inside so-called two-dimensional materials, such as hexagonal boron nitride and black phosphorous, materials with a thickness consisting of only a few atomic layers. They also have shown that it's possible to achieve the dipole-dipole interactions even when the atoms and molecules are relatively distant, with a separation approaching one micron, or 100 times farther apart then would normally be required. This greater distance represents the potential for the practical application of the phenomenon for optical sources.

Findings are detailed in a paper published earlier this year in the journal Nature Communications. The paper was authored by doctoral student Cristian L. Cortes and Jacob.

"Our main goal was trying to understand whether it's possible to control and manipulate these sorts of interactions," Cortes said. "What we found was that by carefully engineering material properties, it is possible to significantly alter the strength and spatial range of these interactions. We found that so-called hyperbolic materials actually allow very long-range interactions unlike any other conventional material."

Dipole-dipole interactions also cause many fluorescent atoms and molecules to emit light in a synchronized manner. Ordinarily, fluorescent molecules emit light in random and spontaneous flashes. However, materials might be engineered to mediate interactions so that the emission becomes synchronized, flashing in unison, and increasing light output dramatically in a phenomenon called super-radiance.

The hyperbolic two-dimensional materials are engineered to induce this super-radiance between fluorescent quantum emitters placed far apart.

"When they are interacting through these materials they can get locked in with each other like two pendulums synchronized perfectly," Jacob said.

The materials are said to be "strongly interacting" due to the long-range dipole-dipole effect.

The "long-range" interactions could make possible new types of light sources that exploit super-radiance. Another challenging goal is to build quantum simulators using a network of interacting emitters to mimic "Coulomb interactions" or "spin interactions" between electrons in a material.

Although the Nature Communications paper focuses on theory, the researchers also suggested several experimental methods to validate the theory. They are performing an experiment using hyperbolic 2-D materials at the Birck Nanotechnology Center in Purdue's Discovery Park. [30]

The inner lives of molecules: New method takes 3-D images of molecules in action

Quantum mechanics rules. It dictates how particles and forces interact, and thus how atoms and molecules work—for example, what happens when a molecule goes from a higher-energy state to a lower-energy one. But beyond the simplest molecules, the details become very complex.

"Quantum mechanics describes how all this stuff works," said Paul Hockett of the National Research Council of Canada. "But as soon as you go beyond the two-body problem, you can't solve the equations." So, physicists must rely on computer simulations and experiments.

Now, he and an international team of researchers from Canada, the U.K. and Germany have developed a new experimental technique to take 3-D images of molecules in action. This tool, he said, can help scientists better understand the quantum mechanics underlying bigger and more complex molecules.

The new method, described in The Journal of Chemical Physics, combines two technologies. The first is a camera developed at Oxford University, called the Pixel-Imaging Mass Spectrometry (PImMS) camera. The second is a femtosecond vacuum ultraviolet light source built at the NRC femtolabs in Ottawa.

Mass spectrometry is a method used to identify unknown compounds and to probe the structure of molecules. In most types of mass spectrometry, a molecule is fragmented into atoms and smaller molecules that are then separated by molecular weight. In time-of-flight mass spectrometry, for example, an electric field accelerates the fragmented molecule. The speed of those fragments depends on their mass and charge, so to weigh them, you measure how long it takes for them to hit the detector.

Most conventional imaging detectors, however, can't discern exactly when one particular particle hits. To measure timing, researchers must use methods that effectively act as shutters, which let particles through over a short time period. Knowing when the shutter is open gives the time-of-flight information. But this method can only measure particles of the same mass, corresponding to the short time the shutter is open.

The PImMS camera, on the other hand, can measure particles of multiple masses all at once. Each pixel of the camera's detector can time when a particle strikes it. That timing information produces a three-dimensional map of the particles' velocities, providing a detailed 3-D image of the fragmentation pattern of the molecule.

To probe molecules, the researchers used this camera with a femtosecond vacuum ultraviolet laser. A laser pulse excites the molecule into a higher-energy state, and just as the molecule starts its quantum mechanical evolution—after a few dozen femtoseconds —another pulse is fired. The molecule absorbs a single photon, a process that causes it to fall apart. The PImMS camera then snaps a 3-D picture of the molecular debris.

By firing a laser pulse at later and later times at excited molecules, the researchers can use the PImMS camera to take snapshots of molecules at various stages while they fall into lower energy states. The result is a series of 3-D blow-by-blow images of a molecule changing states.

The researchers tested their approach on a molecule called C2F3I. Although a relatively small molecule, it fragmented into five different products in their experiments. The data and analysis software is available online as part of an open science initiative, and although the results are preliminary, Hockett said, the experiments demonstrate the power of this technique.

"It's effectively an enabling technology to actually do these types of experiments at all," Hockett said. It only takes a few hours to collect the kind of data that would take a few days using conventional methods, allowing for experiments with larger molecules that were previously impossible.

Then researchers can better answer questions like: How does quantum mechanics work in larger, more complex systems? How do excited molecules behave and how do they evolve?

"People have been trying to understand these things since the 1920s," Hockett said. "It's still a very open field of investigation, research, and debate because molecules are really complicated. We have to keep trying to understand them." [29]

How photons change chemistry

The quantum nature of light usually does not play an important role when considering the chemical properties of atoms or molecules. In an article published in the Proceedings of the National Academy of Sciences scientists from the Max Planck Institute for the Structure and Dynamics of Matter in Hamburg show, however, that under certain conditions, photons can strongly influence chemistry. These results indicate the possibility that chemical processes can be tailored by photons.

Experimentally, such situations have already been observed, but theoretical predictions of the chemical properties of such states were possible only to a limited extent; the common quantum-chemical methods do not take into account the quantum nature of light. The research group has now extended some of these methods to include the coupling to the photons. Among other things, the group of Prof. Angel Rubio showed how strong coupling to photons in an optical cavity changes chemical properties of molecules, like its bond length or its absorption.

"Of special interest," says Johannes Flick, the main author of the work, "are the changes of the Born-Oppenheimer surfaces, which are used to characterize chemical reactions. We found that strong light-matter coupling induces novel reaction pathways." At the same time, the scientists investigated whether standard chemical reactions can be made more efficient by employing strong coupling to the photons. To do so, they considered a simple model of charge transfer between two quantum systems. Such charge-transfer reactions are usually driven by a laser pulse. In this work, the reaction was assisted by a few photons in the optical cavity, which allowed for lower laser intensities.

"Our theoretical findings do not only help to better understand the behavior of atoms and molecules strongly coupled to photons in an optical cavity," says Johannes Flick, "but they also highlight the possibility to change chemical properties via photons." Next, the scientist want to apply their theoretical methods to more complex molecules. The goal is to show that the current results are generally valid and that one can alter the chemical properties of all sorts of molecules via strong light-matter coupling. [28]

Researchers gain control over single atoms

University of Otago physicists have found a way to control individual atoms, making them appear wherever they want them to.

The accomplishment, by a team of six from Otago's Department of Physics, follows an international breakthrough in 2010 when they isolated and captured a neutral rubidium-85 atom, and then photographed it for the first time.

Lead Otago researcher Dr Mikkel Andersen says their results may be beneficial in the future development of a wide range of technologies, including incredibly fast quantum computers for calculations of extreme complexity.

"Time will tell what the applications will be. It is likely the main applications will be in technologies we have not yet thought about."

To achieve their successes, the team uses seven lasers, with components from compact disc players, and precision mirrors.

They work in an air-conditioned laboratory from which as many kinds of "noise" – electromagnetic, sound, temperature contrasts – that can affect the equipment and results have been minimised or eliminated using "Kiwi ingenuity".

Dr Andersen says laser light is the key.

"We cool the atoms, hold them, change how they affect each other and make them visible by shining laser light, with different frequency and intensity, on them. We make repeated use of the phenomenal degree of control one can have over the frequency of laser light, which is a truly astounding feature of lasers.

"The 'Kiwi ingenuity' is how we circumvented the fact that we do not have a low-noise laboratory as would usually be considered a necessity for experiments like ours. Naturally, finding out how to do things that have never been done before involves lots of hard work."

The tables on which the experiment has been built float on air, one way of keeping down the "noise", he says.

Dropping the temperature of the atom to almost absolute zero (minus 273 degrees Celsius), eliminates its "random wobbling", allowing it to reach a quantum state with high purity.

"This represents the ultimate control over individual atoms.

"We are pushing the boundaries for the level of control that scientists can have over microscopic systems. Technical revolutions our society has undergone in past decades largely, if not entirely, originate from being able to control systems at a smaller and smaller scale.

"This has been a long journey. This is what we have been trying to get to for 10 years," Dr Andersen says.

The Marsden Fund supported the research with $717,391 over three years. The team's findings are about to appear in Physical Review A, Rapid Communications.

The next steps are investigations of how two atoms being brought together can exchange properties, and building molecules in particular quantum states from individual atoms. [27]

Measuring entropy on a single molecule

New research shows that a scanning-tunneling microscope (STM), used to study changes in the shape of a single molecule at the atomic scale, impacts the ability of that molecule to make these changes. The study, appearing this week in the journal Nature Communications, demonstrates that the position of the tip of the STM relative to the molecule changes the energy requirements of the molecule to make changes in shape, and in turn, changes the entropy of the system.

“Entropy is often thought of as a measure of disorder or randomness, but here it is determined by the number of shapes that the molecule could potentially take, as well as by the number of different ways that the molecule could meet the energy requirements to change its configuration,” said Eric Hudson, associate professor of physics at Penn State and an author of the paper. “If the tip of the STM increases the energy required by the molecule to make a change in shape, it is also increasing entropy in the system. In essence, a transition requires a potentially large number of small-energy excitations to co-occur to overcome the energy barrier for a configuration change. The larger the number of excitations required, the more ways in which those excitations may be collected. This multiplicity gives rise to entropy.”

“[This result] was totally unexpected,” said Hans Joseph Hug, professor of physics at EMPA, the Swiss Federal Laboratories for Materials Science and Technology and an author of the paper. “It meant that the tip — which is still relatively far away from the molecule and in no-way touches it — somehow influences the molecule’s mobility.”

The rate at the which the molecule “hops” between shapes and the number of possible different shapes that the molecule can take — a representation of the molecule’s entropy — changes depending on the distance between the tip of the STM and the molecule. “This means that the instrument we are using is affecting the system we are trying to study,” said Hudson. “But more importantly, it allows us to measure the molecule’s entropy and the fundamental relationship between entropy and the energy requirements of the molecule to make conformational changes.”

The research team was interested in understanding what drives a molecule’s ability to make changes to its shape — a common requirement of chemical reactions and biological processes. They used an STM, which consists of an extremely fine wire with a sharp tip that can be positioned with sub-atomic precision, to observe changes in the shape of a single molecule of dibutyl-sufide, a lengthy hydrocarbon with a central Sulphur atom, attached to a flat gold surface. Current passes between the tip of the STM and the surface, and as the tip scans across the surface, the STM detects changes in that current as it passes over the molecule. These changes in current are used to produce an image of the molecule.

“At extremely low temperatures — just a few degrees above absolute zero (-273 degrees Celsius or zero degrees Kelvin) — the molecule moves very slowly and the STM captures almost a still image of the molecule,” said Hudson. “But as we raise the temperature even just a few degrees, the molecule moves faster and the image from the STM will show the molecule in more than one conformation. It’s like taking a photograph of a moving object with a slow shutter speed.”

The research team used the STM to observe the changes in shape of the dibutyl sulfide molecule at temperatures ranging from about 5 to 15 degrees Kelvin in order to understand the physical parameters that control the molecule’s ability to change shape. There are two physical parameters that are typically used to describe how free to move a molecule on a surface is: the activation energy, the energy barrier it has to overcome to carry out the movement in question; and the attempt rate, how often the molecule tries to initiate the movement. Surprisingly, the researchers noticed that the energy barrier for the molecule changed depending on the position of the STM tip, even at the same temperatures.

The team also observed that the molecule's attempt rate — which is related to the molecule's entropy — was also impacted by the position of the STM. "This implies that the energy and the entropy in this system are somehow linked at a fundamental level," said Hug. "What's more, our results imply that entropy plays a decisive role for the dynamics of the molecule even at very low temperatures, where a molecule's degree of freedom, and thus its 'configurational' entropy, are usually significantly reduced and entropy is considered to only play a minor role."

"In our study of dibutyl sulfide, the fascinating observation is that raising the hurdle for the molecule's change in shape — the energy barrier for the movement — simultaneously provides it with a greater number of pathways to overcoming it — an increase in entropy," said EMPA physicist Miguel A. Marioni, an author of the paper. "These findings imply that our home-built STM is a perfect tool for studying a single molecule's entropy in great detail."

"To me the thing that is coolest, is that entropy is this fundamental thing that we all learn about in school, but it's never something that you measure," said Hudson. "When you go in the lab it just disappears somehow, so that fact that we were able to measure it, and that the entropic forces are comparable to the forces we typically measure was just mind-blowing."

In addition to Hug, Marioni and Hudson, the research team includes Jeffrey C. Gehrig, Marcos Penedo, and Manfred Parschau, at Johannes Schwenk at EMPA. The research is funded by the Swiss National Science Foundation and EMPA. [26]

Proposed test would offer strongest evidence yet that the quantum state is real

Physicists are getting a little bit closer to answering one of the oldest and most basic questions of quantum theory: does the quantum state represent reality or just our knowledge of reality?

George C. Knee, a theoretical physicist at the University of Oxford and the University of Warwick, has created an algorithm for designing optimal experiments that could provide the strongest evidence yet that the quantum state is an ontic state (a state of reality) and not an epistemic state (a state of knowledge). Knee has published a paper on the new strategy in a recent issue of the New Journal of Physics.

While physicists have debated about the nature of the quantum state since the early days of quantum theory (with, most famously, Bohr being in favor of the ontic interpretation and Einstein arguing for the epistemic one), most modern evidence has supported the view that the quantum state does indeed represent reality.

Philosophically, this interpretation can be hard to swallow, as it means that the many counterintuitive features of quantum theory are properties of reality, and not due to limitations of theory. One of the most notable of these features is superposition. Before a quantum object is measured, quantum theory says that the object simultaneously exists in more than one state, each with a particular probability. If these states are ontic, it means that a particle really does occupy two states at once, not merely that it appears that way due to our limited ability to prepare particles, as in the epistemic view.

What is exactly meant by a limited ability to prepare particles? To understand this, Knee explains that different quantum states must be thought of as distributions over the possible true states of reality. If there is some overlap between these distributions, then the states of reality in which a particle can be prepared is limited.

Currently it's not clear if there actually is any overlap between quantum state distributions. If there is zero overlap, then the particle must really be occupying two states at once, which is the ontic view. On the other hand, if there is some overlap, then it's possible that the particle exists in a state in the overlapping area, and we just can't tell the difference between the two possibilities due to the overlap. This is the epistemic view, and it removes some of the oddness of superposition by plaining that the indistinguishability of two states is a result of overlap (and human limitation) rather than of reality.

Framing the question in terms of overlap offers a way to test the two perspectives. If physicists can show that the indistinguishability of quantum states can somehow be explained by reality and not overlap, then that places tighter restrictions on the epistemic view and makes the ontic view more plausible.

A key to such tests is that the task of discriminating between two states always has a small error involved. Having complete, omniscient knowledge about reality should improve state discrimination. But by how much? This is the big question, and physicists are trying to show that the value of this "improvement due to the increased reality of the quantum states" is very large. This would mean that the overlap plays very little, if any, role in explaining why states are indistinguishable. It's not simply that physicists cannot accurately prepare the true state of reality, it's that the indistinguishability must be thought of as a fundamental property of the quantum states themselves.

Currently, the best experimental data shows that the amount of error improvement that can be attributed to overlap is about 69%. In the new paper, Knee has proposed a way to reduce this value to less than 50% with current technology. As he explains, this would mean that "overlap is doing less than half of the necessary work in explaining the indistinguishability of non-orthogonal quantum states."

"The greatest significance of the work is the new knowledge about how to conduct experiments that can show the reality of the quantum state," Knee told Phys.org. "The big bonuses are that experimentalists will now be able to do more with less: that is, make tighter and tighter restrictions on the possible interpretations of quantum mechanics with fewer experimental resources. These experiments typically require heroic efforts, but the theoretical progress should mean that they are now possible with cheaper equipment and in less time."

To achieve such an improvement, Knee's work addresses one of the biggest challenges in this type of test, which is to identify the types of states and measurements that optimize the error improvement. This is a very high-dimensional optimization problem—with at least 72 variables, it is extremely difficult to solve using conventional optimization methods.

Knee showed that a much better approach to this type of optimization problem is to convert it into a problem that can be studied with convex programming methods. To search for the best combinations of variables, he applied techniques from convex optimization theory, alternately optimizing one variable and then the other until the optimal values of both converge. This strategy ensures that the results are "partially optimal," meaning that no change in just one of the variables could provide a better solution. And no matter how optimal a result is, Knee explains that it may never be possible to rule out the epistemic view entirely.

"There will always be wriggle room!" he said. "Certainly with the techniques known to us at the present time, a small amount of epistemic overlap can always be maintained, because experiments must be finished in a finite amount of time, and always suffer from a little bit of noise. That is to say nothing of the more wacky loopholes that a staunch epistemicist could try and jump through: for example, one can usually appeal to retrocausality or unfair sampling to get around the results of any 'experimental metaphysics.' Nevertheless, I believe that showing the quantum state must be at least 50% real is an achievable goal that most reasonable people would not be able to wriggle out of accepting."

One especially surprising and encouraging result of the new approach is that it shows that mixed states could work better for supporting the ontic view than pure states could. Typically, mixed states are considered more epistemic and lower-performing than pure states in many quantum information processing applications. Knee's work shows that one of the advantages of the mixed states is that they are extremely robust to noise, which suggests that experiments do not need nearly as high a precision as previously thought to demonstrate the reality of the quantum state.

"I very much hope that experimentalists will be able to use the recipes that I have found in the near future," Knee said. "It is likely that the general technique that I developed would benefit from some tweaking to tailor it to a particular experimental setup (for example, ions in traps, photons or superconducting systems). There is also scope for further theoretical improvements to the technique, such as combining it with other known theoretical approaches and introducing extra constraints to learn something of the general structure of the epistemic interpretation. The holy grail from a theoretical point of view would be to find the best possible experimental recipes and prove that they are as much! That is something I will continue to work on." [25]

Physicists realize exotic quantum system robust to mixing by periodic forces

A team of researchers led by LMU physics professor Immanuel Bloch has experimentally realized an exotic quantum system which is robust to mixing by periodic forces.

When James Bond asks the barkeeper for a Martini ("shaken, not stirred"), he takes it for granted that the ingredients of the drink are miscible. If he were to place the order in a bar in the quantum realm, however, Agent 007 might be in for a surprise! For a research team led by physicists Pranjal Bordia, Professor Immanuel Bloch (LMU and Max-Planck-Institute for Quantum Optics) and Professor Michael Knap (TU Munich, Physics Department and Institute for Advanced Study) has now prepared a form of quantum matter that is robust to shaking – a property that would make life difficult for cocktail lovers.

In fact, the problem with quantum matter normally lies in its very sensitivity to perturbation: The action of even weak oscillatory forces typically has drastic consequences in the long term and is expected to dramatically alter its initial state. Therefore – up until now – it had been widely assumed that quantum systems should normally be susceptible to mixing, since shaking injects energy into the system, and should cause it to heat up indefinitely.

But the Munich group has now experimentally characterized an exotic quantum state that does not behave in this way: When subjected to a periodic force, its constituents do not mix. The researchers first cooled a cloud of potassium atoms to an extremely low temperature in a vacuum chamber. They then loaded the ultracold atoms into an optical lattice formed by counter-propagating laser beams that generate standing waves. Such a lattice can be thought of as a network of energy wells in which the atoms can be individually trapped, like the eggs in an egg carton. "In addition, we were able to introduce disorder into the lattice in a controlled manner by randomly altering the depth of the individual wells," says Pranjal Bordia, first author of the new study. By this means, the potassium atoms could be localized in special areas of the network, and were not evenly distributed within the lattice. The physicists then shook the lattice by periodically varying the intensity of the laser light. But the system turned out to be so stable that the localized groups of atoms did not mix. The potassium atoms were tossed about somewhat, but their overall distribution in the lattice remained intact.

The experiments confirm recently published predictions relating to a specific class of quantum systems in which disorder actually serves to localize quantum particles. Moreover, the observation that this newly realized exotic quantum state remained stable for an unexpectedly long time is supported by the results of subsequent high-performance numerical simulations. The experimental demonstration of this quantum system could have practical consequences for efforts to develop robust quantum computers, and studies of exotic quantum states promise to yield new insights into fundamental issues in theoretical physics. [24]

Quantum phase transition observed for the first time

A group of scientists led by Johannes Fink from the Institute of Science and Technology Austria (IST Austria) reported the first experimental observation of a first-order phase transition in a dissipative quantum system. Phase transitions include such phenomena as the freezing of water at the critical temperature of 0 degrees Celsius. However, phase transitions also occur at the quantum mechanical level, where they are still relatively unexplored by researchers.

One example of a phase transition at the quantum level is the photon-blockade breakdown, which was only discovered two years ago. During photon blockade, a photon fills a cavity in an optical system and prevents other photons from entering the same cavity until it leaves, hence blocking the flow of photons. But if the photon flux increases to a critical level, a quantum phase transition is predicted: The photon blockade breaks down, and the state of the system changes from opaque to transparent. This specific phase transition has now been experimentally observed by researchers who, for the first time, met the very specific conditions necessary to study this effect.

During a phase transition, the continuous tuning of an external parameter, for example temperature, leads to a transition between two robust steady states with different attributes. First-order phase transitions are characterized by a coexistence of the two stable phases when the control parameter is within a certain range close to the critical value. The two phases form a mixed phase in which some parts have completed the transition and others have not, as in a glass containing ice water. The experimental results that Fink and his collaborators will publish in the journal Physical Review X give insight into the quantum mechanical basis of this effect in a microscopic, zero-dimensional system.

Their setup consisted of a microchip with a superconducting microwave resonator acting as the cavity and a few superconducting qubits acting as the atoms. The chip was cooled to a temperature astoundingly close to absolute zero—0.01 Kelvin—so that thermal fluctuations did not play a role. To produce a flux of photons, the researchers then sent a continuous microwave tone to the input of the resonator on the chip. On the output side, they amplified and measured the transmitted microwave flux. For certain input powers, they detected a signal flipping stochastically between zero transmission and full transmission, proving the expected coexistence of both phases had occurred. "We have observed this random switching between opaque and transparent for the first time and in agreement with theoretical predictions," says lead author Johannes Fink from IST Austria.

Potential future applications include memory storage elements and processors for quantum simulation. "Our experiment took exactly 1.6 milliseconds to complete for any given input power. The corresponding numerical simulation took a couple of days on a national supercomputer cluster. This gives an idea why these systems could be useful for quantum simulations," Fink explains.

Johannes Fink came to IST Austria in 2016 to start his working group on Quantum Integrated Devices. The main objective of his group is to advance and integrate quantum technology for chip-based computation, communication, and sensing. [23]

Neutrons and a 'bit of gold' uncover new type of quantum phase transition

When matter changes from solids to liquids to vapors, the changes are called phase transitions. Among the most interesting types are more exotic changes—quantum phase transitions—where the strange properties of quantum mechanics can bring about extraordinary changes in curious ways.

In a paper published in Physical Review Letters, a team of researchers led by the Department of Energy's Oak Ridge National Laboratory reports the discovery of a new type of quantum phase transition. This unique transition happens at an elastic quantum critical point, or QCP, where the phase transition isn't driven by thermal energy but instead by the quantum fluctuations of the atoms themselves.

The researchers used a combination of neutron and X-ray diffraction techniques, along with heat capacity measurements, to reveal how an elastic QCP can be found in a lanthanum-copper material by simply adding a little bit of gold.

Phase transitions associated with QCPs happen at near absolute zero temperature (about minus 460 degrees Fahrenheit), and are typically driven at that temperature via factors such as pressure, magnetic fields, or by substituting additional chemicals or elements in the material.

"We study QCPs because materials exhibit many strange and exciting behaviors near the zero temperature phase transition that can't be explained by classical physics," said lead author Lekh

Poudel, a University of Tennessee graduate student working in ORNL's Quantum Condensed Matter Division. "Our goal was to explore the possibility of a new type of QCP where the quantum motion alters the arrangement of atoms.

"Its existence had been theoretically predicted, but there hadn't been any experimental proof until now," he said. "We're the first to establish that the elastic QCP does exist."

"The study of quantum phase transitions is part of a larger effort to study quantum materials that have the potential to be used in devices that move us beyond our current technology paradigms and provide us with transformative functionalities," said ORNL instrument scientist Andrew Christianson.

"Quantum phase transitions are prototypes for generating new quantum phases of matter. In that vein, we're always trying to identify new types of quantum phase transitions as they're one of the ways we find new quantum mechanical behaviors in materials."

To better understand the lanthanum-copper-gold's unique behavior, the team used the Neutron Powder Diffractometer instrument at ORNL's High Flux Isotope Reactor—a DOE Office of Science User Facility—to characterize the material's structure, adding more gold to the composition with each subsequent measurement.

"Neutrons allowed us to look deep into the material at extremely low temperatures to see where the atoms were and how they were behaving," Poudel said.

Researchers already knew that without the presence of gold, lanthanum-copper undergoes a phase transition at roughly 370 degrees Fahrenheit, where the system's crystal structure changes upon cooling. When more gold is added, the transition temperature drops incrementally. Poudel and the team continued to add more gold until the transition temperature reached near absolute zero.

"Because gold atoms have a significantly larger atomic radius than copper atoms, when we add gold to the material, the mismatch of atoms inside the crystal structure suppresses the phase transition to a lower temperature by manipulating the structure's internal strain. At near zero temperature, where thermal energy no longer plays a role in the phase transition, we can see the effects of quantum fluctuations in the motion of the atoms," Poudel said.

The researchers also performed heat capacity measurements, which showed how much heat was needed to change the temperature of the material a few degrees and provided information about the fluctuations in the material.

"Importantly, the combined results show that this is the first example of a potential elastic QCP, where the electronic energy scales don't bear any relevance to the quantum fluctuations," said Andrew May, a researcher in ORNL's Materials Science and Technology Division.

"This elastic QCP in LaCu6-xAux is a perfect example of where the fundamental behavior of a QCP can be studied without the complication of the charge of the electrons, which would probably not be possible in other examples of QCPs," said Poudel. "Now that we've found them, we can more closely study the microscopic fluctuations driving this quantum phase transition and apply other techniques that will give us a greater depth of knowledge about these extraordinary behaviors."

Of the research, University of Tennessee and ORNL joint faculty member David Mandrus said, "This work is a great example of how the University of Tennessee and ORNL can team up to produce first-rate science and deliver an unequaled educational opportunity for a highly motivated Ph.D. student. Success stories such as this will help to attract more young talent to Tennessee, which will benefit both UTK and ORNL."

The paper's authors include Lekh Poudel, Andrew F. May, Michael?R. Koehler, Michael?A. McGuire, Saikat Mukhopadhyay, Stuart Calder, Ryan?E. Baumbach, Rupam Mukherjee, Deepak Sapkota, Clarina dela Cruz, David?J. Singh, David Mandrus and Andrew?D. Christianson.

Complementary contributions were made by the Departments of Physics & Astronomy and Material Science & Engineering at the University of Tennessee, the Department of Physics & Astronomy at the University of Missouri, the National High Magnetic Field Laboratory at Florida State University and Argonne National Laboratory's Advanced Photon Source, a DOE Office of Science User Facility.

The research was supported by DOE's Office of Science, DOE's S3TEC Energy Frontier Research Center, and the National Science Foundation. [22]

Researchers confirm decades-old theory describing principles of phase transitions

New research conducted at the University of Chicago has confirmed a decades-old theory describing the dynamics of continuous phase transitions.

The findings, published in the Nov. 4 issue of Science, provide the first clear demonstration of the Kibble-Zurek mechanism for a quantum phase transition in both space and time. Prof. Cheng Chin and his team of UChicago physicists observed the transition in gaseous cesium atoms at temperatures near absolute zero.

In a phase transition, matter changes its form and properties as in transitions from solid to liquid (for example, ice to water) or from liquid to gas (for example, water to steam). Those are known as first-order phase transitions.

A continuous phase transition, or second-order transition, forms defects—such as domain walls, cosmic strings and textures—where some of the matter is stuck between regions in distinct states. The Kibble-Zurek mechanism predicts how such defects and complex structures will form in space and time when a physical system goes through a continuous phase transition. Examples of continuous phase transitions include the spontaneous symmetry breaking in the early universe and, in the case of the experiment by Chin's team, a ferromagnetic phase transition in gaseous cesium atoms.

"We study phase transitions because it is one of the most fundamental questions that puzzle us," said Chin, a co-author of the paper. "What is the origin of the complex structure of the universe, how do imperfections emerge and how do identical materials develop distinct properties over time?"

Cosmologists who study the origin, evolution, structure and future of the universe also ponder phase transitions in material because it informs their understanding of what occurred throughout the history of the universe—in particular during its formation.

"What we learn from testing KZM in our system is not about the origin of the universe," Chin said. "Rather it is about how complex structure is developed through a transition. These are two different but related questions. You can ask: 'Where does snow come from?' or 'Why do snowflakes have a beautiful crystal structure?' Our investigation is more into the second question."

The findings of the experiment can be applied to many systems—such as liquid crystals, superfluid helium or even cell membranes—that go through similar continuous phase transitions. "All of them should share the same space-time scaling symmetry that we saw here," said Logan Clark, a UChicago doctoral student in physics and first author of the paper.

In the experiment, a vapor of cesium atoms was cooled using laser beams, thereby creating a quantum cesium gas. Additional laser beams were used to create an optical lattice that lined up the atoms of gas in patterns. Sound waves were used to shake the optical lattice and drive the atoms across a continuous, ferromagnetic quantum phase transition. This caused them to divide into different domains with either positive or negative momentum. The researchers found that the structure of the resulting domains was consistent with what the Kibble-Zurek mechanism would have predicted.

"The quantum gas crossing the phase transition in the optical lattice in our experiment is analogous to the entire early universe crossing a phase transition," Clark said. "Any system undergoing a continuous phase transition should share the properties we saw in our experiment."

The patterns that formed depended on how quickly the amount of shaking was ramped up, said Lei Feng, a UChicago doctoral student in physics and a co-author of the paper. "The faster the shaking was ramped up, the smaller the domains. The momentum of the atoms in different regions of the fluid was visible through the microscope, so we could see how big the domains were and count the number of defects between them."

Erich Mueller, professor of physics at Cornell University who is familiar with the research, described the findings as "a remarkable demonstration of the universality of physics."

"The same theory that is used to explain the formation of structure in the early universe also explains the formation of structure in the cold gases" used in their experiments, said Mueller, who did not participate in the study.

The work contributes to the fundamental understanding of physics, Chin said. "While cosmologists are still searching for evidence of the Kibble-Zurek mechanism, our team actually saw it in our lab in samples of atoms at extremely low temperatures.

"We are on the right track to investigate other intriguing cosmological phenomena, not only with a telescope, but also with a microscope," he concluded. [21]

'Exceptional points' give rise to counterintuitive physical effects

No matter whether it is acoustic waves, quantum matter waves or optical waves of a laser—all kinds of waves can be in different states of oscillation, corresponding to different frequencies. Calculating these frequencies is part of the tools of the trade in theoretical physics. Recently, however, a special class of systems has caught the attention of the scientific community, forcing physicists to abandon well-established rules.

When waves are able to absorb or release energy, so-called "exceptional points" occur, around which the waves show quite peculiar behaviour: lasers switch on, even though energy is taken away from them, light is being emitted only in one particular direction, and waves which are strongly jumbled emerge from the muddle in an orderly, well-defined state. Rather than just approaching such an exceptional point, a team of researchers at TU Wien (Vienna, Austria) together with colleagues in Brazil, France, and Israel now managed to steer a system around this point, with remarkable results that have now been published in the journal Nature.

Waves with Complex Frequencies

"Usually, the characteristic frequencies of waves in a particular system depend on several different parameters", says Professor Stefan Rotter (Institute for Theoretical Physics, TU Wien). The frequencies of microwaves in a metal container are determined by the size and by the shape of the container. These parameters can be changed, so that the frequencies of waves are changing as well.

"The situation becomes much more complicated, if the system can absorb or release energy", says Rotter. "In this case, our equations yield complex frequencies, in much the same way as in mathematics, when complex values emerge from the square root of a negative number." At first glance, this may look like a mere technicality, but in recent years new experimental findings have shown that these "complex frequencies" have indeed important physical applications.

Microwaves in a Metal Box

The strange characteristics of these complex frequencies become most apparent when the system approaches an "exceptional point". "Exceptional points occur, when the shape and the absorption of a system can be tuned in such a way that two different waves can meet at one specific complex frequency", Rotter explains.

"At this exceptional point the waves not only share the same frequency and absorption rate, but also their spatial structure is the same. One may thus really interpret this as two wave states merging into a single one at the exceptional point."

Whenever such exceptional points show up in a system, curious effects can be observed: "We send two different wave modes through a wave guide that is tailored not only to approach the exceptional point, but actually to steer the waves around it", says Jörg Doppler, the first author of the study. No matter which one of the two possible modes is coupled into the system - at the output, always the same mode emerges. When waves are coupled into the waveguide from the opposite direction, the other mode is favoured. "It is like driving a car into an icy two-lane tunnel, in which one slides around wildly, but from which one always comes out on the correct side of the road", says Doppler.

In order to test the theoretical models, Stefan Rotter and his group teamed up with researchers in France working on microwave structures, i.e., hollow metal boxes through which electromagnetic waves are sent to study their behaviour. To produce the strange wave behaviour near an exceptional point the waveguides need to follow very special design rules, which were devised at TU Wien with support from Alexei Mailybaev from IMPA (Brazil). The experiments were carried out in the group of Ulrich Kuhl at the University of Nice, where the predicted behaviour could now indeed be observed.

New Frontiers in Wave Physics

Systems with exceptional points open up an entirely new class of possibilities for controlling waves. "Just like complex numbers have brought us new possibilities in mathematics, complex exceptional points give us new ideas for the physics of waves", says Rotter. Indeed, several research groups all over the world are currently working on exceptional points: in the same issue of Nature magazine, in which the above results are published, a team from Yale University (USA) also presents results on exceptional points in opto-mechanics. "I am sure that we will soon hear a lot more about exceptional points in many different areas of physics", says Stefan Rotter. [20]

The birth of quantum holography—making holograms of single light particles

Until quite recently, creating a hologram of a single photon was believed to be impossible due to fundamental laws of physics. However, scientists at the Faculty of Physics, University of Warsaw, have successfully applied concepts of classical holography to the world of quantum phenomena. A new measurement technique has enabled them to register the first-ever hologram of a single light particle, thereby shedding new light on the foundations of quantum mechanics.

Scientists at the Faculty of Physics, University of Warsaw, have created the first ever hologram of a single light particle. The spectacular experiment was reported in the prestigious journal Nature Photonics.The successful registering of the hologram of a single photon heralds a new era of quantum holography, which offers a whole new perspective on quantum phenomena.

"We performed a relatively simple experiment to measure and view something incredibly difficult to observe: the shape of wavefronts of a single photon," says Dr. Radoslaw Chrapkiewicz.

In standard photography, individual points of an image register light intensity only. In classical holography, the interference phenomenon also registers the phase of the light waves—it is the phase that carries information about the depth of the image. When a hologram is created, a well-described, undisturbed light wave—the reference wave—is superimposed on another wave of the same wavelength but reflected from a three-dimensional object. The peaks and troughs of the two waves are shifted to varying degrees at different points of the image. This results in interference and the phase differences between the two waves create a complex pattern of lines. Such a hologram is then illuminated with a beam of reference light to recreate the spatial structure of wavefronts of the light reflected from the object, and as such, its 3D shape.

One might think that a similar mechanism would be observed when the number of photons creating the two waves were reduced to a minimum—that is, to a single reference photon and a single photon reflected by the object. But that is not the case. The phase of individual photons continues to fluctuate, which makes classical interference with other photons impossible. Since the Warsaw physicists faced a seemingly impossible task, they attempted to tackle the issue differently: Rather than using classical interference of electromagnetic waves, they tried to register quantum interference in which the wave functions of photons interact.

Wave function is a fundamental concept in quantum mechanics and the core of its most important principles, the Schrödinger equation. In the hands of a skilled physicist, the function could be compared to putty in the hands of a sculptor. When expertly shaped, it can be used to 'mould' a model of a quantum particle system.

Physicists are always trying to learn about the wave function of a particle in a given system, since the square of its modulus represents the distribution of the probability of finding the particle in a particular state, which is highly useful.

"All this may sound rather complicated, but in practice, our experiment is simple at its core. Instead of looking at changing light intensity, we look at the changing probability of registering pairs of photons after the quantum interference," explains doctoral student Jachura.

Why pairs of photons? A year ago, Chrapkiewicz and Jachura used an innovative camera built at the University of Warsaw to film the behaviour of pairs of distinguishable and non-distinguishable photons entering a beam splitter. When the photons are distinguishable, their behaviour at the beam splitter is random—one or both photons can be transmitted or reflected. Non-distinguishable photons exhibit quantum interference, which alters their behaviour. They join into pairs and are always transmitted or reflected together. This is known as two-photon interference or the Hong-Ou-Mandel effect.

"Following this experiment, we were inspired to ask whether two-photon quantum interference could be used similarly to classical interference in holography in order to use known-state photons to gain further information about unknown-state photons. Our analysis led us to a surprising conclusion: it turned out that when two photons exhibit quantum interference, the course of this interference depends on the shape of their wavefronts," says Dr. Chrapkiewicz.

Quantum interference can be observed by registering pairs of photons. The experiment needs to be repeated several times, always with two photons with identical properties. To meet these conditions, each experiment started with a pair of photons with flat wavefronts and perpendicular polarisations; this means that the electrical field of each photon vibrated in a single plane only, and these planes were perpendicular for the two photons. The different polarisation made it possible to separate the photons in a crystal and make one of them 'unknown' by curving their wavefronts using a cylindrical lens.

Once the photons were reflected by mirrors, they were directed toward the beam splitter (a calcite crystal). The splitter didn't change the direction of vertically-polarised photons, but it did diverge diplace horizontally polarised photons. In order to make each direction equally probable and to make sure the crystal acted as a beam splitter, the planes of photon polarisation were bent by 45 degrees before the photons entered the splitter. The photons were registered using the state-of-the-art camera designed for the previous experiments. By repeating the measurements several times, the researchers obtained an interference image corresponding to the hologram of the unknown photon viewed from a single point in space. The image was used to fully reconstruct the amplitude and phase of the wave function of the unknown photon.

The experiment conducted by the Warsaw physicists is a major step toward improving understanding of the fundamental principles of quantum mechanics. Until now, there has not been a simple experimental method of gaining information about the phase of a photon's wave function. Although quantum mechanics has many applications, and it has been verified many times with a great degree of accuracy over the last century, we are still unable to explain the nature of wave functions—are they simply a handy mathematical tool, or are they something real?

"Our experiment is one of the first allowing us to directly observe one of the fundamental parameters of photon's wave function—its phase—bringing us a step closer to understanding what the wave function really is," explains researcher Michal Jachura.

The Warsaw physicists used quantum holography to reconstruct wave function of an individual photon. Researchers hope that in the future, they will be able to use a similar method to recreate wave functions of more complex quantum objects, such as certain atoms. Will quantum holography find applications beyond the lab to a similar extent as classical holography? Such existing practical applications include security (holograms are difficult to counterfeit), entertainment, transport (in scanners measuring the dimensions of cargo), microscopic imaging and optical data storing and processing technologies.

"It's difficult to answer this question today. All of us—I mean physicists—must first get our heads around this new tool. It's likely that real applications of quantum holography won't appear for a few decades yet, but if there's one thing we can be sure of it's that they will be surprising," summarises Prof. Konrad Banaszek. [19]

Study suggests a flaw in traditional theory that describes photodissociation process

A combined team of researchers from Columbia University in the U.S. and the University of Warsaw in Poland has found that there appear to be flaws in traditional theory that describe how photodissociation works. In their paper published in the journal Nature, the team describes how they took a different approach to studying what happens when light causes molecules to break apart and what they observed by doing so. David Chandler with Sandia National Laboratories offers a historical perspective and an analysis of the work done by the team in a News & Views piece in the same journal issue.

Scientists have known for some time that light is able to cause molecules to break apart—oxygen molecules are broken apart in the atmosphere by sunlight, for example, but understanding how exactly the process works has been an ongoing project. Up till now, researchers have studied the process by irradiating a very cold supersonic molecular beam. This technique has suffered from the problem of not being able to create a beam that was low enough in temperature to allow for molecular pieces to be manipulated in a truly quantum state; instead they have had to rely on averaging results. In this new effort, the team developed a technique that allowed for tracking the disassociation at much slower speeds, which allowed them to get a better look at what actually occurs.

To get a slower look, the researchers used an optical lattice to hold a group of strontium-88 atoms in a group, which were brought together by photo absorption, resulting in excited molecules. The team allowed the molecules to decay to their lowest quantum state, then excited them to specific states which allowed for studying them as they were exposed and broken apart by pulses of laser light. Doing so allowed the team to view a purely magnetic transition for the first time, and also to see that not all of the pieces of the shattered molecule flew perpendicular or parallel to the direction of the light source, which Chandler notes "can only be described by a full quantum-mechanical treatment of the light-absorption process."

The team next plans to conduct similar experiments using molecules brought to higher energy states to learn more about the ways in which the molecules behave in ways that seem more classical than quantum. [18]

Researchers explore the billiard dynamics of photon collisions

When one snooker ball hits another, both spring away from each other in an elastic manner. In the case of two photons, a similar process, the elastic collision, has never been observed. Physicists from the Institute of Nuclear Physics of the Polish Academy of Sciences have shown, however, that such a process does not only occur, but could even soon be registered in heavy ion collisions at the LHC accelerator.

When photons collide with each other, do they act like billiard balls, springing away from each other in different directions? Such a course of interaction between particles of light has never been observed, even in the LHC, the most powerful accelerator in the world. An observation may, however, happen soon, thanks to a highly detailed analysis of the course of events in such a collision, conducted by physicists from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Krakow, Poland, published in the journal Physical Review C.

Preliminary analysis of the elastic scattering of a photon-photon collision was presented several years ago in a study by scientists from the European Organization for Nuclear Research (CERN). Krakow scientists, however, have examined the process in much finer detail. Not did they establish that collisions occur, they have taken into account more mechanisms of interaction between photons and predicted the directions in which most photons will scatter post-collision—and whether they can be measured. The results suggest that at least some of the photons deflected as a result of elastic collisions should hit the detectors installed by the ATLAS, CMS and ALICE projects. If the described phenomenon actually occurs, and by all appearances it will, observation would become possible within the next few years.

"Elastic collisions of photons with photons seemed, until recently, very unlikely. Many physicists regarded the registration of such collisions in the LHC as impossible. Meanwhile, we have proven that the phenomenon can be seen, though not in the collisions of protons, which occur much more frequently", says Prof. Antoni Szczurek (IFJ PAN).

The LHC collides beams of protons with protons, or lead nuclei beams with lead nuclei. The IFJ PAN had shown earlier that if the collisions of protons occurred for elastic collisions between photons, the process would not be visible—it would obscure photons emitted by a different mechanism (initiated by gluons, the particles carrying the strong nuclear force). Luckily, the Polish scientists had some other ideas in store.

According to the rules of classical optics, light cannot be affected by light. Photons, however, can interact with each other through quantum processes. When two photons fly next to each other within that extremely short instant, there is nothing preventing the creation of 'virtual' loops of quarks or leptons (which include electrons, muons, tau particles, neutrinos and the antiparticles associated with them). Such particles would be termed virtual, as they would be impossible to see.

However, despite this, they would be responsible for the interaction between photons, after which they would again be transformed into 'real' photons. To the outside observer, the whole process would look like one photon reflected by the other photon.

Unfortunately, the energy of the photons generated by even the most powerful contemporary light sources can be registered only in millions of electron volts. These are miniscule values, even by the standards of modern nuclear physics and particle physics. At these energies, the probability of a collision with a photon-photon quantum process is infinitesimal, and the streams of photons necessary for its occurence would have to be colossal.

"In this situation, we decided to see whether elastic collisions of photons involving virtual particles can occur during collisions of heavy ions. And it worked! Large electric charges in the nuclei of lead may, in fact, lead to the creation of photons. If the process occurs in collisions of nuclei which have just passed, the photon generated by one nucleus has a chance to collide with photons produced by the second. We calculated that the probability of such a course of events is admittedly small, but nonzero. So everything indicates that the process could be observed," says Dr. Mariola Klusek-Gawenda.

Interestingly, the collisions studied theoretically by the Krakow physicists were very specific, as they did not analyze direct collisions of lead nuclei with one another as such, but processes without direct contact between nuclei. Interaction occurs between the electromagnetic fields of two atomic nuclei, which can fly even from long distances between them. These collisions are known as ultra-peripheral.

Potentially, photons can interact with each other as a result of another process—when a quantum transforms into virtual mesons, or quark-antiquark pairs. The mesons produced could interact with each other via the strong nuclear force, the fundamental force responsible for binding quarks inside protons and neutrons. The physicists from the IFJ PAN were the first to present this mechanism. It seems, however, that the observation of light collision with participation at the event will not be possible: The gentle photons bouncing off each other just fly next to the detectors currently operating at the LHC.

The study of photon-photon elastic collisions not only provides a better understanding of known physics. Quantum processes carrying the interaction between photons could potentially be involved as elementary particles, something we do not yet know. So if measurements of elastic scattering of photons off photons provided results other than those predicted by Krakow physicists, this could be a signal leading to a completely new physics engaged in the phenomena. [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."

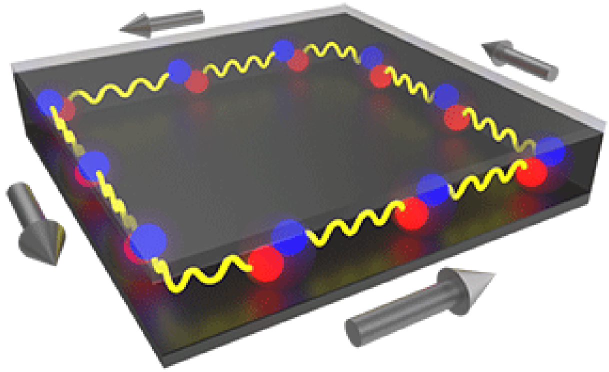
The researchers found that the rate for non-radiative energy transfer from individual quantum dots to tin disulfide increases with an increasing number of tin disulfide layers. But performance in laboratory tests isn't enough to prove the merits of potential new materials. So the scientists incorporated 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 Chang-Yong 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 polarition, 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 though 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) $I = I_0 \sin^2 n\,\phi/2\ \mathbf{/}\ \sin^2 \phi/2$

If ϕ is infinitesimal so that $\sin\phi = \phi$, than

(2) $I = n^2 I_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

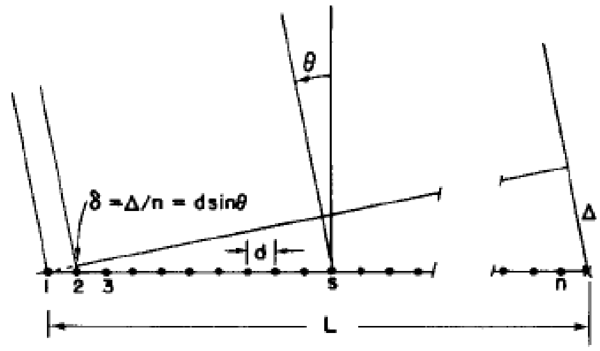


Fig. 30–3. A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.

Figure 1.) A linear array of n equal oscillators

There is an important feature about formula (1) which is that if the angle ϕ is increased by the multiple of 2π, it makes no difference to the formula.

So

(4) $d \sin \theta = m \lambda$

and we get m-order beam if λ less than d. [6]

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

For example

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

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 (λ), Planck's law is written as:

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

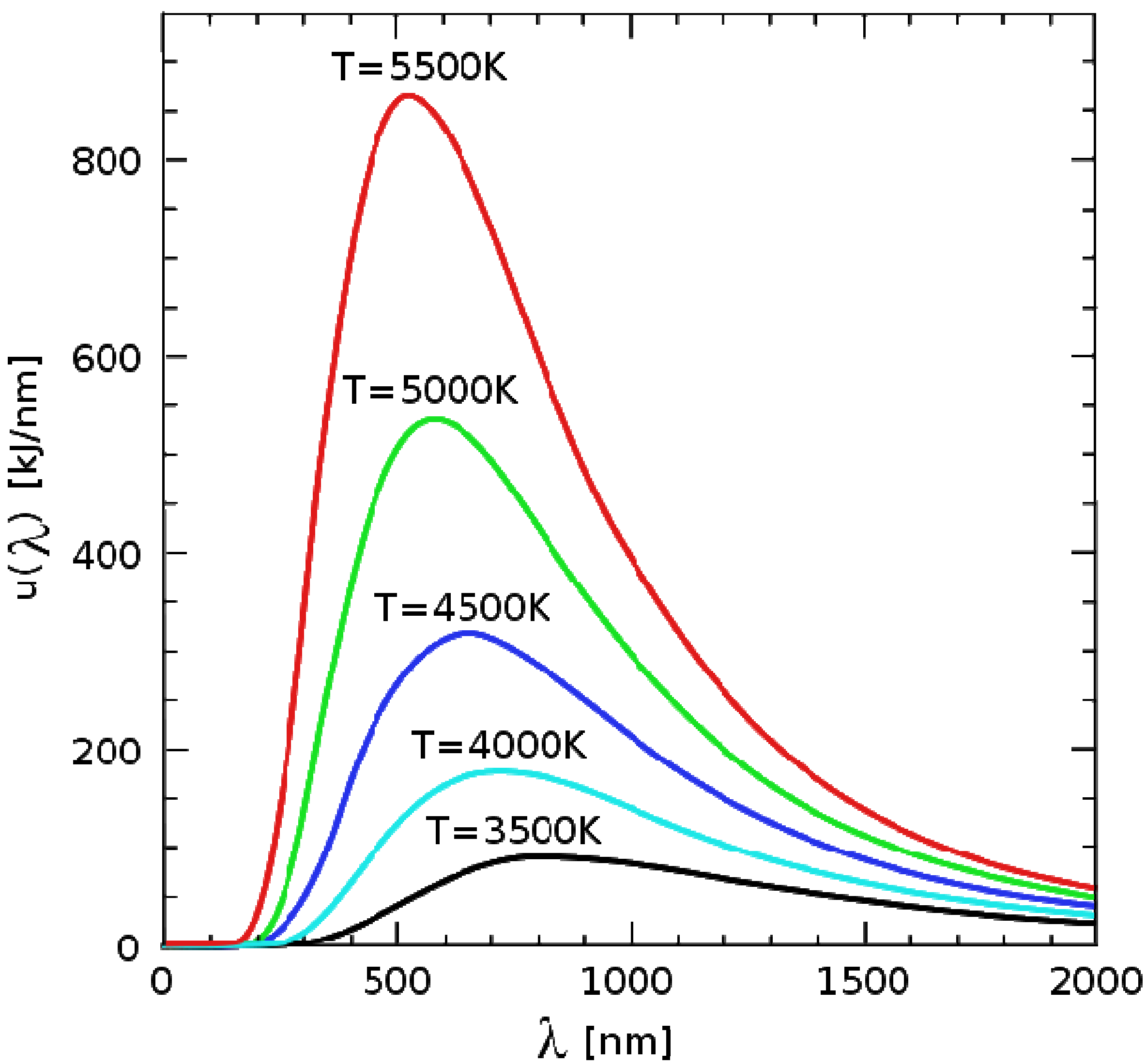


Figure 2. The distribution law for different T temperatures

We see there are two different λ_1 and λ_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 λ_{max} is the annihilation point where the configurations are symmetrical. The λ_{max} is changing by the Wien's displacement law in many textbooks.

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

> where λ_{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 $2.8977685(51)\times10^{-3}$ m·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 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

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

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

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

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

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

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

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of

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

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

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

There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction. [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 h = d x d p or 1/2 h = d t d 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 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The 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 week 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 dx and raising the dp. 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 rate since the dx is much less requiring bigger dp 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 Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

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

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

The mass as seen before a result of the diffraction, for example the proton – electron mass rate 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 (ν) 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 ν, wavelength λ, 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 e 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 rate 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 one-dimensional (1D) equations, such as the nonlinear Schrödinger equation, that describe solitons in a variety of wave contexts, including matter waves1, 2. 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 rate 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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