Giant Bubbles of Fluid Mechanics

A study inspired by street performers making gigantic soap bubbles led to a discovery in fluid mechanics: Mixing different molecular sizes of polymers within a solution increases the ability of a thin film to stretch without breaking. [39]

Organic chemists at The Ohio State University have figured out how to synthesize the most common molecule arrangement in medicine, a scientific discovery that could change the way a number of drugs—including one most commonly used to treat ovarian cancer—are produced. [38]

Determining the optimal binding energies for heterogeneous chemical reactions—usually meaning that the reactant is in the gas or liquid phase while the catalyst is a solid—is critical for many aspects of modern society, as we rely on such reactions for processes as diverse as the production of fertilizers and plastics. [37]

Among the many techniques being investigated to generate clean energy, water splitting is a very promising one. [36]

But now, Shigehisa Akine and colleagues from Kanazawa University have shown that the reversed order is also possible: first, the host undergoes a chemical reaction, after which it recognizes and forms a complex with the guest ion. [35]

In batteries, fuel cells or technical coatings, central chemical processes take place on the surface of electrodes which are in contact with liquids. During these processes, atoms move over the surface, but how this exactly happens has hardly been researched. [34]

A team of scientists from across the U.S. has found a new way to create molecular interconnections that can give a certain class of materials exciting new properties, including improving their ability to catalyze chemical reactions or harvest energy from light. [33]

A team of scientists including Carnegie's Tim Strobel and Venkata Bhadram now report unexpected quantum behavior of hydrogen molecules, H_2, trapped within tiny cages made of organic molecules, demonstrating that the structure of the cage influences the behavior of the molecule imprisoned inside it. [32]

A potential revolution in device engineering could be underway, thanks to the discovery of functional electronic interfaces in quantum materials that can self-assemble spontaneously. [31]

Now, for the first time ever, researchers from Aalto University, Brazilian Center for Research in Physics (CBPF), Technical University of Braunschweig and Nagoya University have produced the superconductor-like quantum spin liquid predicted by Anderson. [30]

Electrons in graphene—an atomically thin, flexible and incredibly strong substance that has captured the imagination of materials scientists and physicists alike—move at the speed of light, and behave like they have no mass. [29]

In a series of exciting experiments, Cambridge researchers experienced weightlessness testing graphene's application in space. [28]

Scientists from ITMO University have developed effective nanoscale light sources based on halide perovskite. [27]

Physicists have developed a technique based on optical microscopy that can be used to create images of atoms on the nanoscale. [26]

Researchers have designed a new type of laser called a quantum dot ring laser that emits red, orange, and green light. [25]

The world of nanosensors may be physically small, but the demand is large and growing, with little sign of slowing. [24]

In a joint research project, scientists from the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI), the Technische Universität Berlin (TU) and the University of Rostock have managed for the first time to image free nanoparticles in a laboratory experiment using a highintensity laser source. [23]

For the first time, researchers have built a nanolaser that uses only a single molecular layer, placed on a thin silicon beam, which operates at room temperature. [22]

A team of engineers at Caltech has discovered how to use computer-chip manufacturing technologies to create the kind of reflective materials that make safety vests, running shoes, and road signs appear shiny in the dark. [21]

In the September 23th issue of the Physical Review Letters, Prof. Julien Laurat and his team at Pierre and Marie Curie University in Paris (Laboratoire Kastler Brossel-LKB) report that they have realized an efficient mirror consisting of only 2000 atoms. [20]

Physicists at MIT have now cooled a gas of potassium atoms to several nanokelvins—just a hair above absolute zero—and trapped the atoms within a two-dimensional sheet of an optical lattice created by crisscrossing lasers. Using a high-resolution microscope, the researchers took images of the cooled atoms residing in the lattice. [19]

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

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

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

Light from an optical fiber illuminates the metasurface, is scattered in four different directions, and the intensities are measured by the four detectors. From this measurement the state of polarization of light is detected. [15] Converting a single photon from one color, or frequency, to another is an essential tool in quantum communication, which harnesses the subtle correlations between the subatomic properties of photons (particles of light) to securely store and transmit information. Scientists at the National Institute of Standards and Technology (NIST) have now developed a miniaturized version of a frequency converter, using technology similar to that used to make computer chips. [14]

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

Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological 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

Physics of giant bubbles bursts secret of fluid mechanics

A study inspired by street performers making gigantic soap bubbles led to a discovery in fluid mechanics: Mixing different molecular sizes of polymers within a solution increases the ability of a thin film to stretch without breaking.

The journal *Physical Review Fluids* published the results of the study by physicists at Emory University. The findings could potentially lead to improving processes such as the flow of oils through industrial pipes and the clearance of polluting foams in streams and rivers.

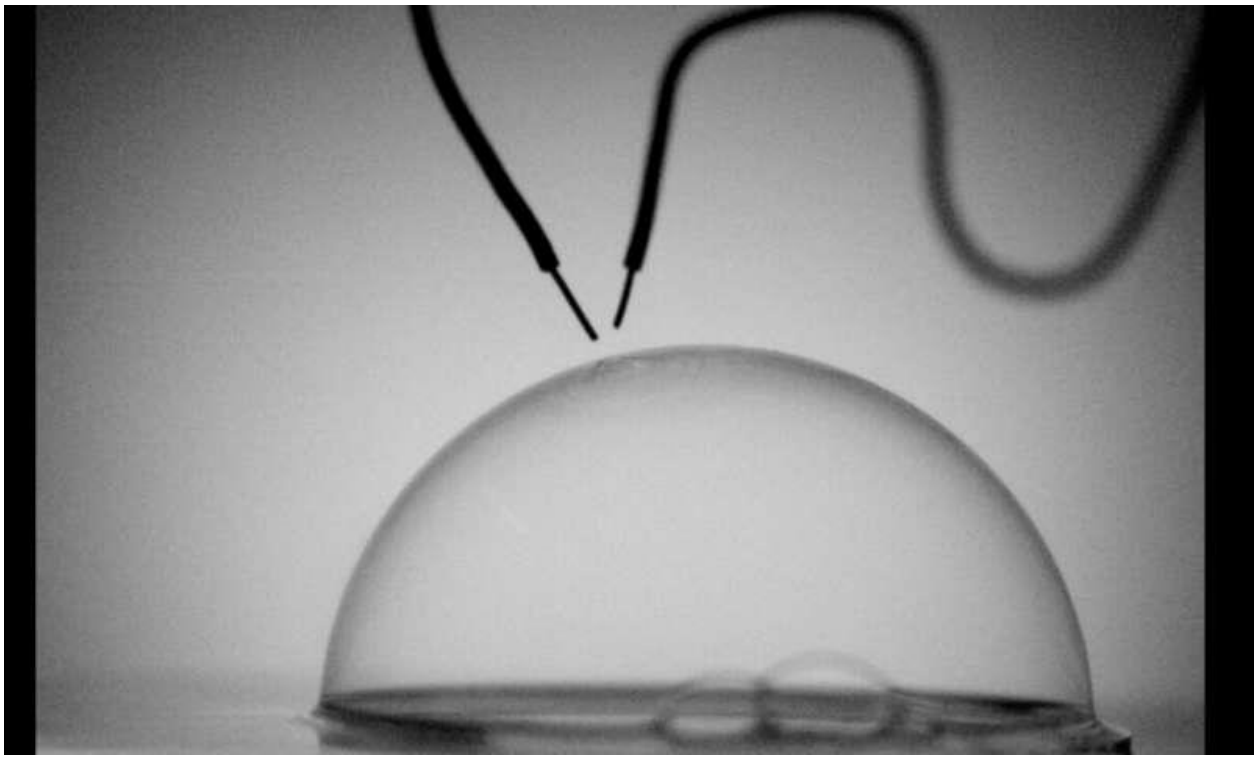
The results also hold implications for backyard bubble-blowing enthusiasts.

"This study definitely puts the fun into fundamental science," says Justin Burton, associate professor of physics at Emory University and senior author of the paper.

Fluid dynamics is one of the focuses of Burton's lab. "The processes of fluid dynamics are visually beautiful and they are everywhere on our planet, from the formation and breakup of droplets and bubbles to the aerodynamics of airplanes and the deep-sea overturning of the world's oceans," he says.

While Burton was in Barcelona for a conference a few years ago, he happened to see street performers making huge bubbles using a soap solution and thick cotton string. "These bubbles were about the diameter of a hula hoop and as much as a car-length long," he recalls. "They were also beautiful, with color changes from red to green to bluish tones on their surface."

This rainbow effect shows that a film's thickness is comparable to the wavelength of light, or just a few microns, he explains.



A lab experiment measures the forces as a soap bubble bursts. Credit: Burton lab video

Viewing the performance sparked a physics question in Burton's mind: How could such a microscopically thin film maintain its integrity over such a large distance without breaking up? He began investigating, both in his backyard and in his lab.

As Burton researched bubble recipes he came across the Soap Bubble Wiki, an online, open-source project. The wiki states that it aims to help "bubblers" create "the perfect bubble" by separating fact from folklore regarding soap bubble-making recipes and ingredients.

In addition to water and dishwashing liquid, the Soap Bubble Wiki recipes usually included a polymer—a substance made up of long chains of repeating molecules. The most common polymers in the recipes were natural guar, a powder used as an additive in some foods, or industrial polyethylene glycol (PEO), a lubricant used in some medicines. Guided by the wiki recommendations, Burton conducted laboratory experiments along with two student co-authors who have since graduated: Stephen Frazier, who received a master's in physics in May and is first author, and undergraduate Xinyi Jiang.

"We basically started making bubbles and popping them, and recorded the speed and dynamics of that process," Burton says. "Focusing on a fluid at its most violent moments can tell you a lot about its underlying physics."

Soap films absorb infrared light, so the researchers shone it through the bubbles to measure the thickness of the films. They also measured the molecular weights of the different polymers they used in the bubble recipes. And they let gravity pull droplets of the various soap films off a nozzle, in order to measure how long the resulting thread of liquid could stretch between the nozzle and the droplet before breaking.

The results revealed that polymers were the key ingredient to making colossal bubbles. The long, fibrous strands of polymers enable the bubbles to flow smoothly and stretch further without popping.

"The polymer strands become entangled, something like a hairball, forming longer strands that don't want to break apart," Burton explains. "In the right combination, a polymer allows a soap film to reach a 'sweet spot' that's viscous but also stretchy—just not so stretchy that it rips apart."

The work confirms what many expert "bubblers" already had figured out—a good giant soap bubble recipe should include a polymer.

"We did the physics to explain why and how polymers can make a fluid film stretch as far as 100 square meters without breaking," Burton says.

The physicists also found that varying the molecular sizes of the polymers helps strengthen soap film. That discovery happened by accident.

The researchers worked on the project for more than a year and stored some containers of PEO they had purchased. They realized that PEO from containers that had aged about six months produced stronger soap bubble films compared to PEO from containers used when it was first purchased. Upon investigation, they realized that the polymers in the aged PEO had degraded over time, varying the length of the molecular strands.

"Polymers of different sizes become even more entangled than single-sized polymers, strengthening the elasticity of the film," Burton says. "That's a fundamental physics discovery."

Understanding how fluids and thin films response to stress, Burton says, could lead to an array of applications, such as improving the flow of industrial materials through pipes, or the clean-up of toxic foams.

"As with all fundamental research, you have to follow your instincts and heart," Burton says of his soap bubble odyssey. "Sometimes your bubble gets burst, but in this case, we discovered something interesting." [39]

Chemists find new way of creating the building blocks of many drugs

Organic chemists at The Ohio State University have figured out how to synthesize the most common molecule arrangement in medicine, a scientific discovery that could change the way a number of drugs—including one most commonly used to treat ovarian cancer—are produced.

Their discovery, published today in the journal *Chem*, gives drug makers a crucial building block for creating medicines that, so far, are made with complex processes that result in a lot of waste.

This new finding may allow drug makers to create this building block in just one step, said David Nagib, the study's senior author and assistant professor in the Department of Chemistry and Biochemistry at Ohio State.

A drug's molecules must interact in just the right way with the molecules inside the human body to be effective. It's like when two people meet: Each person must use their right hand to shake hands with each other. If one person tries to use their left hand, it just doesn't work.

"Another way to look at it is that drugs work like a lock and key, and you have to put a left-handed key into a left-handed lock," Nagib said.

The most common arrangement of molecules used in drugs so they can interact effectively with human molecules is called a chiral piperidine.

Currently, drug makers synthesize this molecule arrangement using a circuitous process that involves creating a mixture and essentially throwing half that mixture out.

"Previously, there was no available method that simply swapped a single carbon-hydrogen bond for a carbon-carbon bond like this," said Zuxiao Zhang, the study's lead author and a postdoctoral researcher in Nagib's lab. "And what we figured out is, through free radicals, we can make this happen."

The heart of their discovery lies in the chemical bonds that make up a molecule. The researchers considered a number of drugs and looked at the way their molecules are created. One, the anti-cancer drug niraparib—a pill used to treat ovarian cancer—uses a chiral piperidine. But to produce it, the drug's makers have to create a number of symmetric mixtures, then strip parts away until they get to the asymmetric molecule necessary to make the drug effective.

Creating that chiral six-sided ring synthetically was a problem that had troubled chemists for decades. It was so tricky, in fact, that when Zhang first approached Nagib about tackling it, Nagib was unsure it was the right problem to solve.

"The success of this chemistry was entirely thanks to Zuxiao's courage and ambition to tackle such a hard problem," Nagib said.

It is a fundamental change that Nagib hopes might make a number of medicines easier to produce.

"It's a different way of doing things," he said. "It's like flying an airplane over the Atlantic. Is that a shortcut, instead of having a boat? Yes, it's a more efficient way of going, but it's also a fundamentally different way. If you fly across the Atlantic, now you can do other things—you can fly other places. That's what this." [38]

Scientists recalculate the optimum binding energy for heterogeneous catalysis

Determining the optimal binding energies for heterogeneous chemical reactions—usually meaning that the reactant is in the gas or liquid phase while the catalyst is a solid—is critical for many aspects of modern society, as we rely on such reactions for processes as diverse as the production of fertilizers and plastics.

There is an optimal binding energy—meaning the degree of interaction between the reactants and the catalyst—where the process is most efficient (if it is too low, the reactants will not react with the catalyst, and if it is too high they will remain bound to it), and catalysts are designed based on this.

Now, in a discovery that could lead to the development of novel catalysts that do not rely on expensive rare metals, scientists from the RIKEN Center for Sustainable Resource Science have shown that the optimal binding energy can deviate from traditional calculations, which are based on equilibrium thermodynamics, at high reaction rates. This means that reconsidering the design of catalysts using the new calculations may be necessary to achieve the best rates.

Heterogeneous chemical reactions are used in many industrial processes. Some of the best known are the production of ammonia via the Haber-Bosch process, the production of plastics using the Ziegler-Natta reaction, and the desulfurization of petroleum. In 1911, the French chemist Paul Sabatier proposed, based on experiments, that there is an optimum binding energy which allows the catalytic activity to be maximized. Recently, advances in computational chemistry have provided a framework with which to calculate the optimal binding energy, based on equilibrium thermodynamics and assuming that the process will proceed smoothly if all steps in the process are thermodynamically favorable. Here, the role of the catalyst is to improve the thermodynamics of the most unfavorable step. The catch is that "optimum" is usually understood as meaning that the reaction requires as little driving force as possible, so that it is thermodynamically efficient, but in the real world it is often more practical to have a higher rate of catalysis, even if a larger driving force is necessary.

The team performed a new set of calculations, based on reaction kinetic modeling, that take this discrepancy into account, and calculated new optimal binding energies for hydrogen oxidation, which uses heterogeneous catalysis, finding that the calculations gave different values at high reaction rates. "We were happy to see," says Hideshi Ooka, the first author of the study, "that our calculations predict new strategies of catalyst design which could not have been obtained using the traditional, thermodynamic approach."

According to Ryuhei Nakamura, head of the Center for Sustainable Resource Center's Biofunctional Catalyst Research Team, "Based on this finding, we plan to look for new catalysts, using elements such as copper or nickel, that can push heterogeneous catalytic reactions forward but are less costly and more environmentally friendly than the current ones, which often require precious metals such as platinum and palladium."

He continues, "Consequently, research to find new catalysts using our method could contribute to reaching three of the United Nations Sustainable Development Goals: Goal 7 (affordable and clean energy), Goal 12 (responsible production and consumption), and Goal 13 (climate action)."

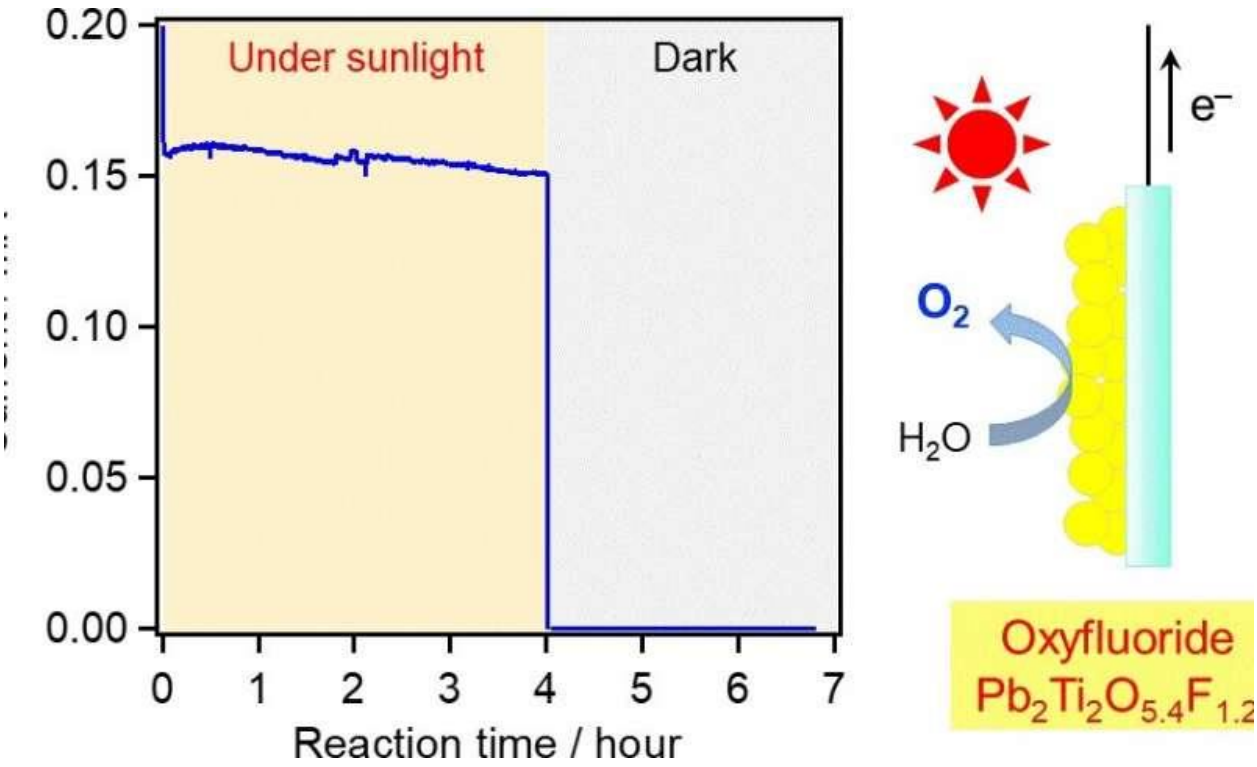
The study is published in The *Journal of Physical Chemistry Letters*. [37]

Breaking water molecules apart to generate clean fuel: Investigating a promising material

In line with the increasing global concerns about the state of our planet, perfecting the technology for alternative energy generation has become a hot topic among researchers worldwide. Among the many techniques being investigated to generate clean energy, water splitting is a very promising one. In particular, water (H_2O) can be split to obtain dihydrogen (H_2) by using solar energy; this is known as photoelectrochemical water splitting. Dihydrogen can be used as clean fuel for other machines or to generate electricity, which means that improving our water-splitting techniques is a guaranteed way to reduce our carbon emissions and alleviate global warming.

How does photoelectrochemical water splitting work? In short, as shown in Fig. 1, one way to do it is to use a certain type of semiconductor material, which is called the photoanode, and connect it to a small voltage source and a metal wire, which acts as the cathode. When exposed to sunlight, water is divided into its constituting atoms on these two ends; the constituent atoms recombine to form the useful H_2 and O_2 as a byproduct. The crucial step here is finding stable, high-performance materials for the photoanode because the oxidation sub-step, which involves the formation of O_2, is the most difficult one.

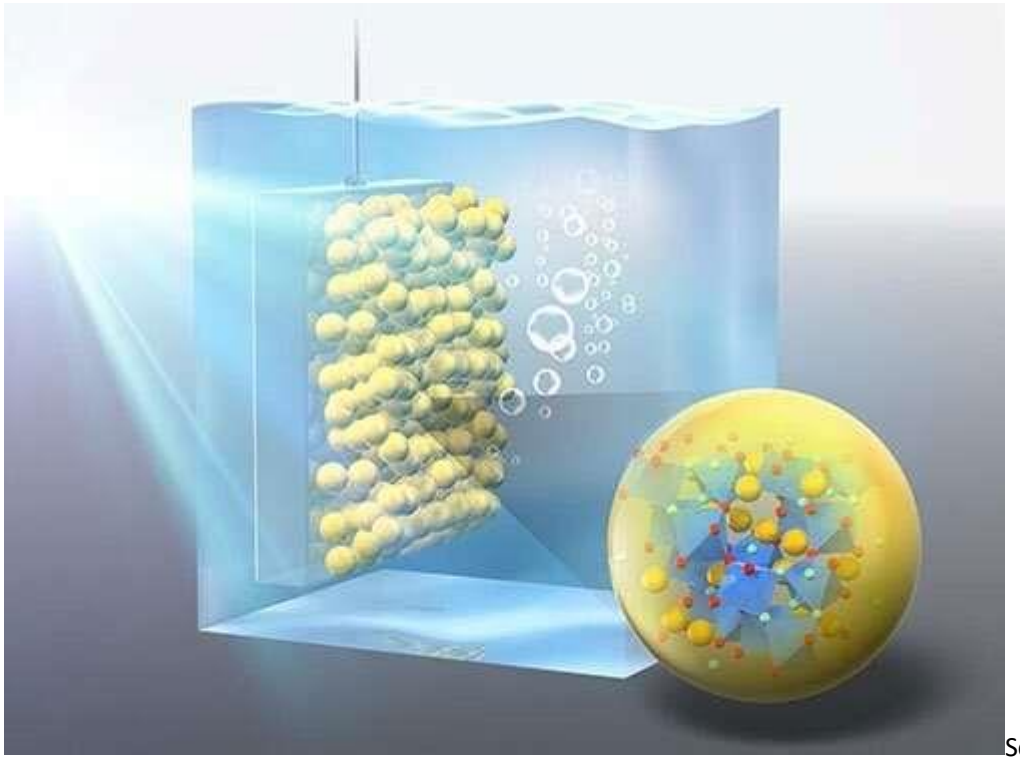
Unfortunately, most research has focused on a class of photoanodes called oxynitrides, which suffer from instability and degrade relatively quickly because they are prone to oxidize when illuminated by light. To address this issue, a team of researchers from Tokyo Tech led by Prof. Kazuhiko Maeda focused instead on another type of photoanode material, an oxyfluoride with the chemical formula $Pb_2Ti_2O_{5.4}F_{1.2}$. This compound does not suffer from self-oxidation due to its electronic properties.



Performance of the proposed photoanode. The oxyfluoride compound $Pb_2Ti_2O_{5.4}F_{1.2}$ appears very promising

as a photoanode after appropriate surface modifications. The graph shows the generated current under sunlight, which directly translates to the generation of H_2 on the cathode on the other side of the circuit. Credit: Tokyo Tech

While this oxyfluoride has been reported to be promising for many other applications, there were no studies on its photoelectrochemical performance as a photoanode for water splitting. The research team studied this compound under various lighting and applied-voltage conditions, and found that, to use it as a photoanode, it is necessary to modify its surface with other compounds. First, a layer of titanium oxide (TiO_2) has to be deposited on the surface of the oxyfluoride to increase the photocurrent generated by the water-splitting reaction. Then, the performance of the photoanode can be greatly enhanced by further coating it with cobalt oxides (CoOx), which penetrate through the cracks in the TiO_2 layer and promote the desired reaction. "Post-modification of the photoanode with a water-oxidation promoter has proven to be indispensable to attaining stable performance in most cases," remarks Prof. Maeda.



Schematic illustration of photoelectrochemical water splitting on $Pb_2Ti_2O_{5.4}F_{1.2}$ electrode. Appeared in the journal as the graphical abstract. Credit: Tokyo Tech

The researchers performed several experiments to characterize their photoanode and its performance for water splitting under a variety of conditions, such as under different types of light and different voltage and pH values (which is a measure of the acidity of water). Their results are promising (Fig. 2) and very useful to point other researchers toward the right direction. "So far, oxynitrides and similar compounds have been viewed as promising but difficult-to-handle materials for photoanodes because of their inherent instability to self-oxidation. $Pb_2Ti_2O_{5.4}F_{1.2}$ represents a long-awaited breakthrough in this regard," concludes Prof. Maeda. Water splitting technology may be crucial for meeting our energy needs without further harming

the environment, and studies like this one are essential stepping stones to reach our goals for a greener future. [36]

Controlling ion recognition in reactive host-guest systems

Sometimes a molecule can only undergo a particular chemical reaction if it forms a so-called host-guest complex together with another molecule—the two molecules are then bound together not by covalent bonds but by intermolecular forces. What happens is that first, the host recognizes the guest, after which it can chemically react and become another molecule.

But now, Shigehisa Akine and colleagues from Kanazawa University have shown that the reversed order is also possible: first, the host undergoes a chemical reaction, after which it recognizes and forms a complex with the guest ion. Moreover, they found that the order of recognition and reaction can be switched by modifying the guest ion. Distinguishing between the two alternatives ('recognition first' or 'reaction first') becomes important when the timescale on which the two processes happen differ significantly, a situation that could be exploited in applications including drug delivery.

For their study, the researchers used a cobalt-containing host molecule (a 'metallohost'), which has a cavity that can accommodate a particular ion (charged atom) as a guest. The metallohost can undergo reactions of the type known as ligand exchange reaction. The advantage of using this host system is that the occurring reaction processes are slow, and easily monitorable by nuclear magnetic resonance (NMR) spectroscopy. As a guest ion, Akine and colleagues used a compound named NaOTf, containing a sodium ion, which can occupy the host's cavity when forming the host-guest complex.

After adding NaOTf to the metallohost, the NMR signal did not initially point to a structural change. However, after three hours, a change did occur, indicating the formation of new molecules. To determine whether the process was 'recognition first' or 'reaction first', the researchers examined the kinetics of the ligand exchange reaction, and its relation to the sodium concentration. They found that the reaction speed increased significantly with increasing the concentration of sodium, which made them conclude that for sodium the mechanism was 'recognition first'.

Akine and colleagues performed similar experiments with potassium- and rubidium-based guest compounds. Interestingly, they observed that the ligand exchange then occurred in the guest-free form, meaning that the overall process was 'reaction first'.

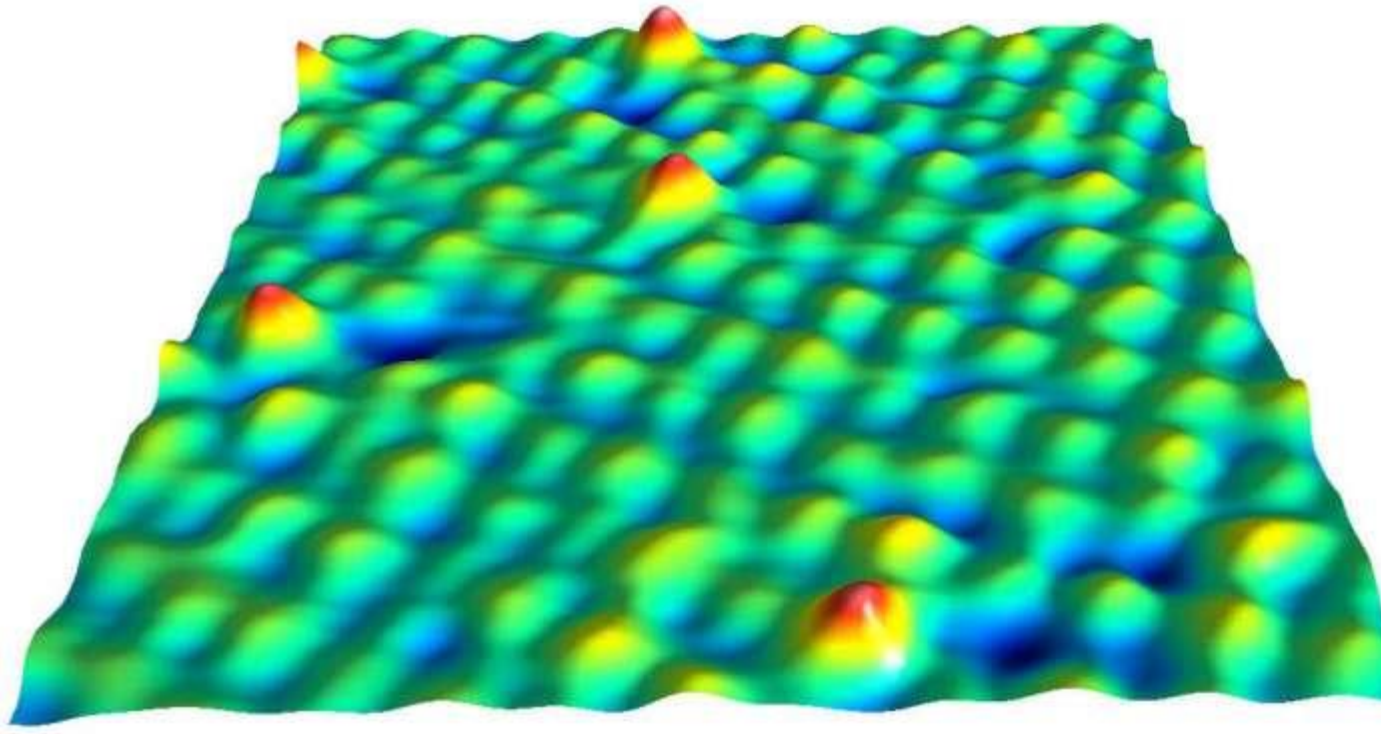
The observed dependence of the type of binding taking place on the type of guest metal ion not only add new insights into host-guest chemistry and their dynamics, but may also lead to applications. The scientists believe that "the understanding of the mechanism would help in developing new time-programmable guest uptake/release systems such as drug delivery systems." [35]

Physics team investigates influence of ions on atomic motions

In batteries, fuel cells or technical coatings, central chemical processes take place on the surface of electrodes which are in contact with liquids. During these processes, atoms move over the surface, but how this exactly happens has hardly been researched. Physicists at Kiel University want to gain a better understanding of these motions, and the role of the chemical components involved. To do so, they observe with highest microscopic resolution how sulphur atoms move on copper electrodes, which are immersed in different saline solutions. Microscopic video recordings showed that these movements are controlled by ions, attached to the surface of the electrode. These findings could help to control such motion processes precisely, for example to optimise coating processes in the microelectronics industry. The results of this study are published in the current issue of the renowned scientific journal *Angewandte Chemie*.

Processes at interfaces are similar to a football game in a stadium: the team on the field must score the goals, but the support of the spectators probably also has an influence on the course of the game. "Ions or molecules that attach to a surface, can have a decisive influence on reactions occurring there, even if they are not directly involved," said Professor Olaf Magnussen, head of the Interface Physics Group at the Institute of Experimental and Applied Physics. In chemistry, these atoms are known as "spectator species". However, the exact influence of such atomic "spectators" on reactions at interfaces is, in most cases, only partly known. Further knowledge could help to control these processes better.

In their experiment, the research group investigated copper electrodes in saline solutions, containing either chlorine or bromine ions. These ions accumulated as "spectators" on the copper surface. The researchers then added small quantities of sulphur atoms, and observed their thermal motion on the surface of the electrode. To do so, they used a special scanning tunnelling microscope, which can make single atoms visible - even in saline solutions. Since this works only at temperatures above freezing the atoms move relatively fast, the microscopic pictures thus have to be taken in a short time.

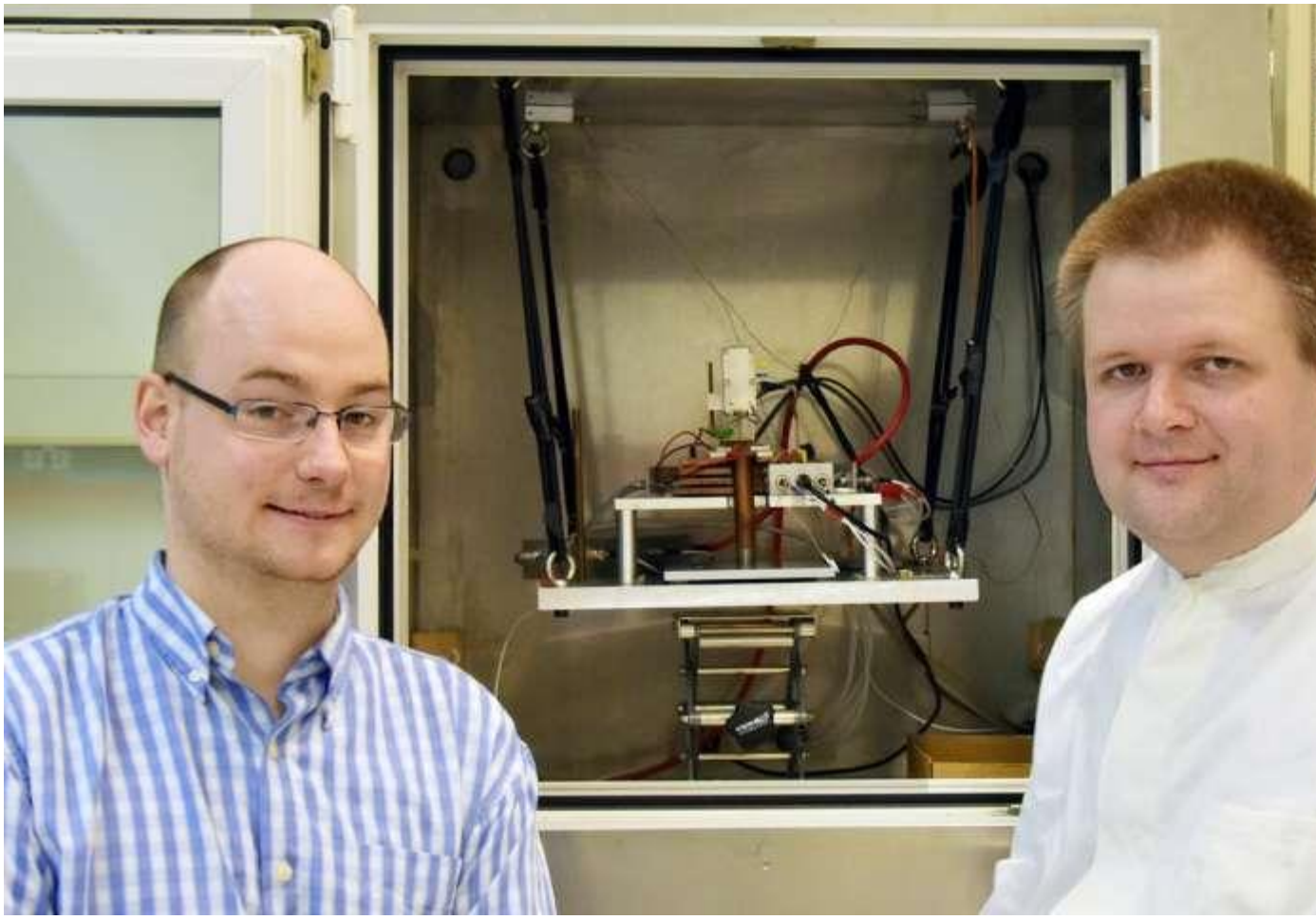


The recording of the scanning tunnelling microscope shows sulphur atoms (red) on a copper electrode, surrounded by bromine ions (green). Credit: Rahn

In the scanning tunnelling microscope, a tiny metal tip scans the electrode, and thereby creates an image of its surface. Standard instruments can take one image per minute. Over several years, the Kiel working group further developed their microscope so that their instrument can generate up to 20 images per second. With this worldwide unique instrument, it is possible to capture in a video how atoms move on a surface.

The resulting recordings surprised the research team: in both saline solutions, the speed of the sulphur atoms was strongly influenced by the voltage applied to the electrode. Even an increase of just 1/10 of a volt made them move ten times faster. However, higher voltage made the sulphur atoms move slower on the surface with chloride ions, but faster on the surface covered with bromide. "Chloride and bromide are chemically very similar - we had not expected this different behaviour," said Björn Rahn, who carried out these investigations as part of his doctoral thesis supervised by Magnussen.

Clues to an explanation for these different observations were provided by computer simulations, produced by the working group of Professor Eckhard Pehlke from the Institute of Theoretical Physics and Astrophysics. "Sulphur atoms behaves so differently on surfaces with chloride and bromide ions, because the two ions trigger different motion mechanisms," said Pehlke, to explain his team's calculations.



Doctoral researcher Björn Rahn (right) from the Interface Physics Group carried out the experiments with the scanning tunnelling microscope. Lukas Deuchler, who is currently a doctoral researcher in theoretical physics, simulated the atomic …more

While sulphur atoms in the presence of chloride ions move only on the surface the calculations for the surface with bromide ions suggests that sulphur atoms briefly dip into the metal surface while changing their positions.

The computer simulations confirm that the bromide and chloride ions on the surface are more than just passive spectators, and instead directly influence the chemical processes. These fundamental research findings do not just help to gain a better understanding of elementary processes at interfaces. "Our results are also a first step towards better controlling such electrochemical processes," said Magnussen, looking ahead. [34]

What a mesh

A team of scientists from across the U.S. has found a new way to create molecular interconnections that can give a certain class of materials exciting new properties, including improving their ability to catalyze chemical reactions or harvest energy from light.

In a new study, researchers at the U.S. Department of Energy's (DOE) Argonne National Laboratory, the University of California-Los Angeles, the University of California-Santa Barbara, Purdue University and the University of Oregon have developed a method to create linked networks of metal oxides that could have interesting catalytic or electronic properties.

Metal oxides are of interest to scientists because of their unique electronic and chemical properties. Some, like titanium dioxide, are commonly used in photovoltaic and photocatalytic applications because of their ability to absorb light.

The key to forming these metal oxide networks is boron, which when annealed with metal oxides leads to the formation of thermally robust and stable interconnected clusters that act as strands of glue that connect a metal oxide web.

"This glue has the ability to be a key component of the entire reactive system, changing the properties that the metal oxides had on their own," said Alexander Spokoyny, a chemist at UCLA.

The formation of the boron-metal oxide network provides a launching point for future studies of different materials that could combine their own natural properties with the added advantage of a similar "cross-linked" structure.

"We want to know, for instance, if we can transfer our knowledge of this mesh to a material like silicon dioxide. The photocatalytic properties of these materials are extraordinary compared to titanium dioxide," said Argonne chemist Max Delferro.

In the future, the researchers seek to design a way to create precisely tailored materials by perfecting how the interconnecting clusters of boron "glue" are interspersed within the metal oxide. "If we can stitch in these molecules exactly where we want them to be, it will give us a powerful ability to make and understand hybrid materials with a wide range of uses," Spokoyny said.

Because these materials are so new, the researchers believe they have a great deal of untapped potential. "We're not claiming mission fully accomplished by any means; there are still parts of the chemistry that we don't fully understand and appreciate," Delferro said.

The research team included Argonne chemist Karena Chapman, who works at the laboratory's Advanced Photon Source (APS), a DOE Office of Science User Facility. Chapman and Spokoyny met when they were named to *Chemical and Engineering News*'s "Talented Twelve" list in 2016, and established the collaboration that led to the research.

According to Chapman, a member of the Structural Sciences Group in the APS X-ray Science division, the structural characterization of the material involved the use of X-ray pair distribution function analysis carried out at the APS, which gives local structural information about the relative atom positions.

Chapman, Delferro and Spokoyny noted that the efforts of the research team to produce and analyze this new material were just as interconnected as the discovered hybrid material itself. "There are cross-linkages at both the molecular and the human level," Delferro said. "This work proves that we work better and are stronger when we're connected."

A paper based on the research, "A Molecular Cross-Linking Approach for Hybrid Metal Oxides," appeared in the March 5 issue of *Nature Materials*. [33]

Molecular prison forces diatomic inmates to cell floor

A team of scientists including Carnegie's Tim Strobel and Venkata Bhadram now report unexpected quantum behavior of hydrogen molecules, H_2, trapped within tiny cages made of organic molecules, demonstrating that the structure of the cage influences the behavior of the molecule imprisoned inside it.

A detailed understanding of the physics of individual atoms interacting with each other at the microscopic level can lead to the discovery of novel emergent phenomena, help guide the synthesis of new materials, and even aid future drug development.

But at the atomic scale, the classical, so-called Newtonian, rules of physics you learned in school don't apply. In the arena of the ultra-small, different rules, governed by quantum mechanics, are needed to understand interactions between atoms where energy is discrete, or non-continuous, and where position is inherently uncertain.

The research team—including Anibal Ramirez-Cuesta, Luke Daemen, and Yongqiang Cheng of Oak Ridge National Laboratory, as well as Timothy Jenkins and Craig Brown of the National Institute of Standards and Technology-used spectroscopic tools, including the state-of-the-art inelastic neutron spectrometer called VISION at the Spallation Neutron Source, to examine the atomic-level dynamics of a special kind of molecular structure called a clathrate.

Clathrates consist of a lattice structure that forms cages, trapping other types of molecules inside, like a molecular-scale prison. The clathrate the team studied, called β-hydroquinone, consisted of cages made from organic molecules that trap H_2. Only a single H_2 molecule is present within each cage, so the quantum behavior of the isolated molecules could be examined in detail.

"Practical examples of isolated quantum-influenced particles that are trapped inside well-defined spaces provide the opportunity to probe dynamics under conditions that are approaching simulation-like perfection," Strobel explained.

The research team was able to observe how the hydrogen molecule rattled and rotated within the cage. Surprisingly, the observed rotational motion was unlike that of H_2 trapped in related systems in which molecules can rotate almost freely in all directions.

"The behavior we observed here is similar to the behavior of H_2 molecules that are adhering to a metal surface," Strobel explained. "It is the first time this behavior, known by physicists as a two-dimensional hindered rotor, has been observed for hydrogen trapped within a molecular clathrate."

It turns out that the local structure of the clathrate cage greatly influences the dynamics of H_2, causing a preference for rotation in two dimensions despite the fact that there are no chemical bonds involved. In addition to the fundamental insights, this discovery could have important implications for the design of hydrogen storage materials that can trap H_2 for energy and transportation applications. [32]

Self-assembling, tunable interfaces found in quantum materials

A potential revolution in device engineering could be underway, thanks to the discovery of functional electronic interfaces in quantum materials that can self-assemble spontaneously.

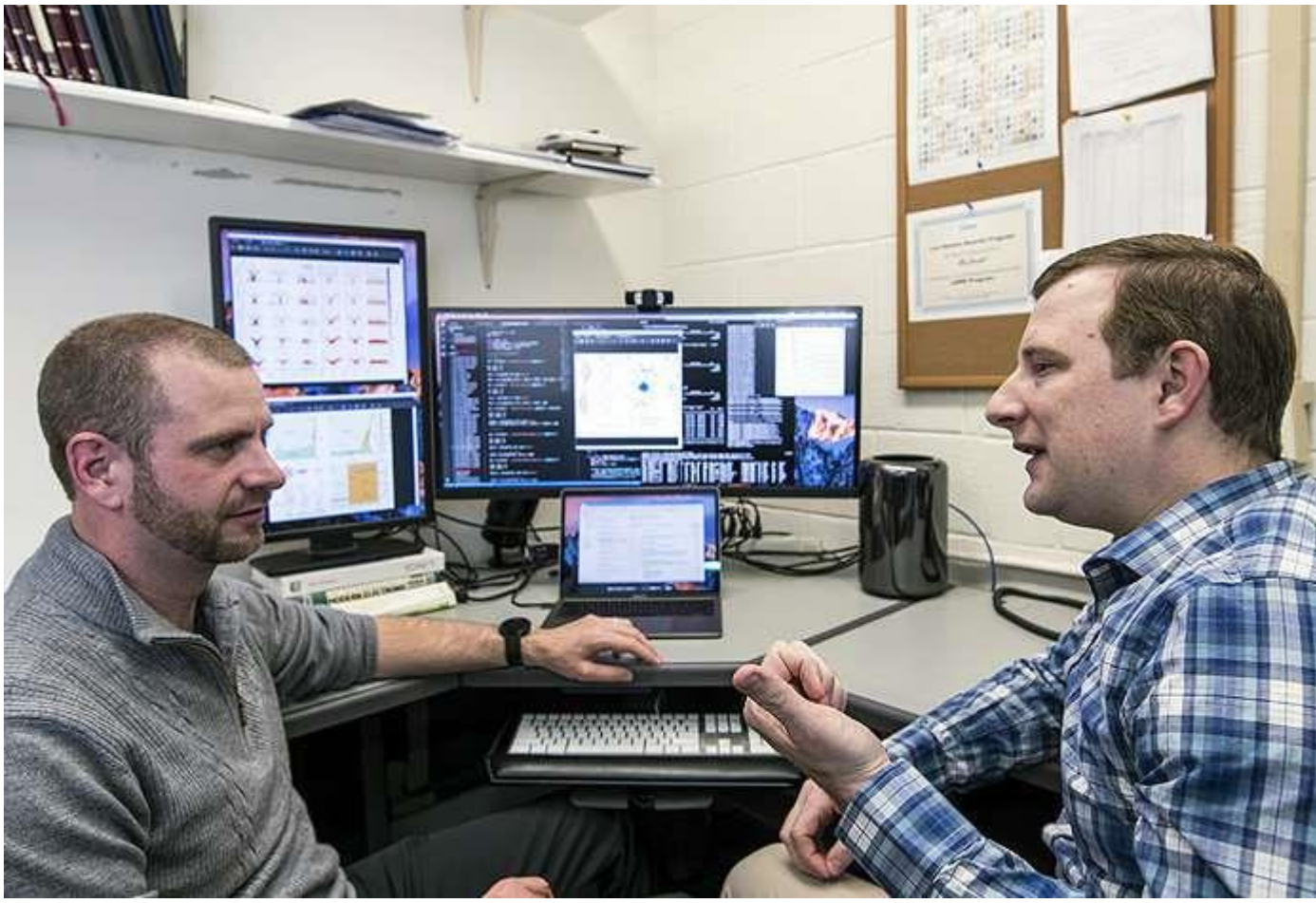
"This illustrates that if we can learn to control and exploit the remarkable properties at the interfaces of quantum materials, this will likely result in a new generation of devices beyond our current imagination," said Marc Janoschek, a physicist at Los Alamos National Laboratory who, with David Fobes, also of Los Alamos, co-led the international research team making the discovery. Their findings were published today in *Nature Physics*. "However, because quantum materials are chemically much more complex compared to 'conventional' materials such as semiconductors, it remains a challenge to fabricate clean quantum material interfaces."

Materials with properties characterized by the laws of quantum mechanics rather than classical mechanics often have features such as superconductivity. But extensive research has shown that at interfaces between two materials, the remarkable properties of quantum materials can be strongly enhanced or entirely new functional properties may arise.

An example of the importance of material interfaces would be transistors, whose function is based on physical effects occurring at semiconductor interfaces artificially engineered via techniques such as lithography. Transistors form the foundation for the current generation of electronic devices.

The complexity of quantum materials is often characterized by the competition of various interactions on the quantum level.

"Here we showed that at the same time this complexity also provides a solution," said Fobes, who carried out his postdoctoral research under the supervision of Janoschek. Fobes and Janoschek led the international team of researchers that combined extensive neutron spectroscopy measurements from Oak Ridge National Laboratory's (ORNL) Spallation Neutron Source (SNS), National Institute of Standards and Technology's (NIST) Center for Neutron Research (NCNR), United Kingdom's Neutron and Muon Source (ISIS), and at the Munich Research Reactor II (FRM II) of the Heinz-Mayer-Leibnitz Zentrum in Germany with detailed theoretical modeling.



Marc Janoschek, left, and David Fobes discuss features of quantum materials. Credit: Los Alamos National Laboratory

"Neutron spectroscopy measurements were crucial to demonstrating that in certain metals, the competition between various interactions may be resolved by the spontaneous formation of a state in which the electronic and magnetic properties alternate periodically," said Georg Ehlers, the ORNL scientist who performed spectroscopy measurements at SNS.

This periodic arrangement leads to interfaces between alternating material layers that are akin to interfaces in engineered heterostructures. However, the spontaneously self-assembling interfaces identified in this study have major advantages; they are intrinsically clean, and relevant parameters such as the interface thickness can be tuned in-situ via external parameters such as magnetic field or temperature.

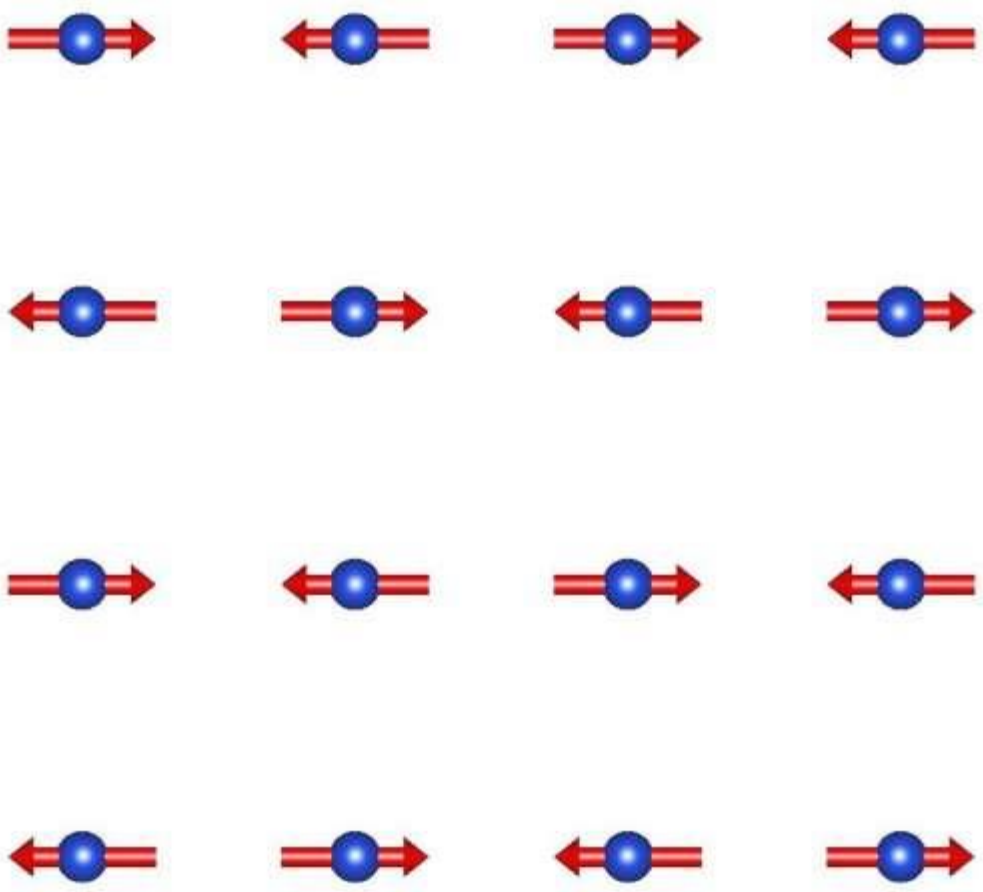
The basic ingredients identified by Fobes and the team are common to several classes of quantum materials and suggest that these intrinsic and tunable interfaces may be more frequent. Learning to control the self-assembly of such intrinsic quantum interfaces, in turn, has the potential to revolutionize device design, where devices are not fabricated but spontaneously form via quantum engineering of the underlying atomic-scale interactions. In addition, these devices could be tuned and reconfigured using external parameters, possibly allowing for the design of highly adaptive electronics. [31]

Theoretical quantum spin liquid prepared for the first time

In 1987, Paul W. Anderson, a Nobel Prize winner in physics, proposed that high-temperature superconductivity, or loss of electrical resistance, is related to an exotic quantum state now known as quantum spin liquid. Magnetic materials are made up of very tiny magnets, which can be as small as individual electrons. The strength and direction of these are described by the magnetic moment. In quantum spin liquids, magnetic moments behave like a liquid and do not freeze or order even at absolute zero. These quantum states are being studied as promising materials for new, so-called topological quantum computers, in which operations are based on particle-like excited states found in quantum spin liquids. In addition to large computational power, a topological quantum computer is characterised by high fault tolerance, which makes it possible to increase the size of the computer. However, only a few quantum spin liquids suitable for topological quantum computers have been identified so far.

Now, for the first time ever, researchers from Aalto University, Brazilian Center for Research in Physics (CBPF), Technical University of Braunschweig and Nagoya University have produced the superconductor-like quantum spin liquid predicted by Anderson. This is an important step towards understanding superconductors and quantum materials. The preparation of a quantum spin liquid was made possible by a new way of tailoring the properties of magnetic materials that was developed by chemists at Aalto University. The results of the research have been published in *Nature Communications*.

High-temperature superconductors are copper oxides in which the copper ions form a square lattice so that the adjacent magnetic moments face in opposite directions. When this structure is disturbed by changing the oxidation state of copper, the material becomes superconducting. In the new research now published, the magnetic interactions of this square structure were modified with ions with a d10 and d0 electronic structure, which turned the material into a quantum spin liquid.



The magnetically ordered square lattice of copper ions. Tailoring the structure caused the formation of quantum spin liquid. Modifying the structure in a different way results in high-temperature superconductivity. Credit: Otto Mustonen

"In the future, this new d10/d0 method can be utilised in many other magnetic materials, including various quantum materials," says Doctoral Candidate Otto Mustonen from Aalto University.

Seamless cooperation

Empirical detection of quantum spin liquids is difficult and requires extensive research infrastructure.

"We used muon spin spectroscopy in the this study. This method is based on the interaction of very short-lived, electron-like elementary particles, known as muons, with the material being studied. The method can detect very weak magnetic fields in quantum materials," says Professor F. Jochen Litterst from the Technical University of Braunschweig. The measurements were performed at the Paul Scherrer Institute in Switzerland.

"In addition to top-class equipment, the research requires seamless cooperation between chemists and physicists," says Professor Maarit Karppinen. "We're going to need the same international multidisciplinary approach in the future so that this research on quantum spin liquids can lead us to the experimental realization of the topological quantum computer." [30]

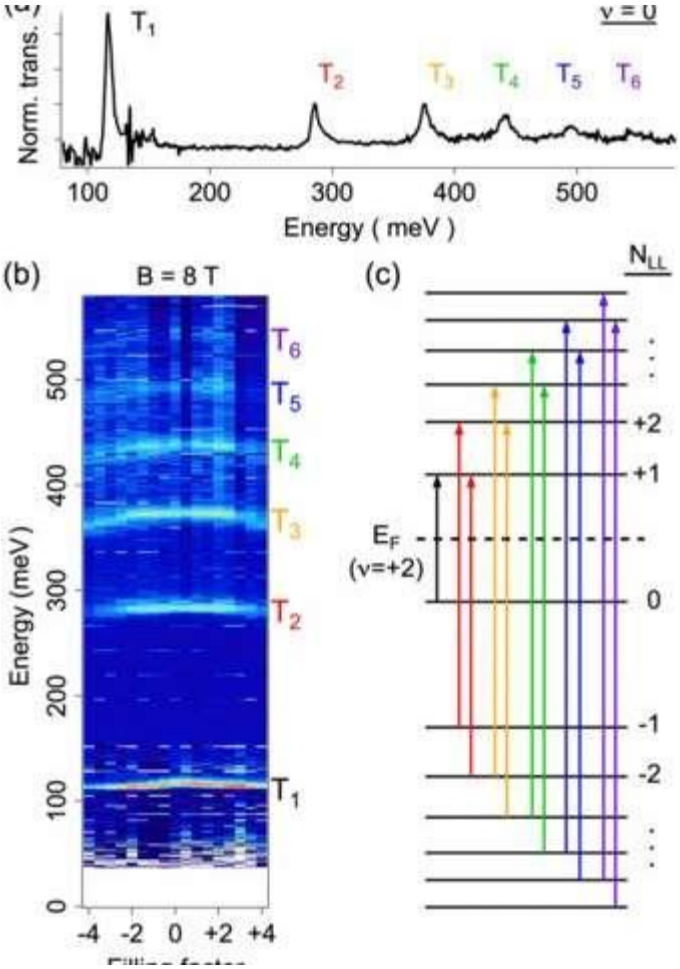
New view on electron interactions in graphene

Electrons in graphene—an atomically thin, flexible and incredibly strong substance that has captured the imagination of materials scientists and physicists alike—move at the speed of light, and behave like they have no mass. Now, scientists at Washington University in St. Louis have demonstrated how to view many-particle interactions in graphene using infrared light. The research will be presented at the American Physical Society meeting this week in Los Angeles.

Deep in the sub-basement below Washington University's historic Crow Hall, a research team led by Erik Henriksen, assistant professor of physics in Arts & Sciences, conducts its work in a custom-built vessel cooled to a few degrees above absolute zero. They use a small sliver of graphene sandwiched between two boron-nitride crystals and placed on top of a silicon wafer; at approximately 16 microns long, the entire stack of material is less than one-sixth the size of a human hair.

"Here we have constructed a system that narrowly focuses infrared light down to the sample, which is inside a large magnet and at very low temperature," Henriksen said. "It allows us to literally shine a flashlight on it, and explore its electronic properties by seeing which colors of light are absorbed."

Graphene has generated a lot of excitement in the materials-science research community because of its potential applications in batteries, solar energy cells, touch screens and more. But physicists are more interested in graphene because of its unusual electron structure, under which its electrons behave like relativistic particles.



Interband Landau level transitions in monolayer. Credit: arXiv:1709.00435

Under normal conditions, electrons always mutually repel each other. Henriksen and his team study how this behavior changes when the electrons seem to have no mass.

By gathering simultaneous measurements of optical and electronic properties in the presence of a high magnetic field, the researchers were able to track the movement of charged particles between orbits with discrete energy values, called Landau levels. A pattern began to emerge.

"A strong magnetic field provides a kind of glue to their motion—it slows them down in some ways," Henriksen said. "You would think it would be a very difficult system to look at. But sometimes, at very specific ranges of the magnetic field strength and the interaction strength, you'll find that, all of a sudden, the system simplifies enormously."

"You would expect a flat line, essentially, in the absence of these interesting interactions that we're looking for," said Jordan Russell, a doctoral candidate in physics and co-author of a new paper on graphene. "This non-monotonic behavior is a signature of the interactions we were looking for."

The March Meeting of the American Physical Society is expected to bring together nearly 10,000 condensed-matter physicists. Other recent work from Henriksen's lab will also be showcased at this forum,

including a recent discovery that graphene can be used to measure a "quantum spin liquid" in magnetic materials. [29]

Zero gravity graphene promises success in space

In a series of exciting experiments, Cambridge researchers experienced weightlessness testing graphene's application in space.

Working as part of a collaboration between the Graphene Flagship and the European Space Agency, researchers from the Cambridge Graphene Centre have tested graphene in microgravity conditions for the first time.

Testing graphene's potential in cooling systems for satellites, the researchers experienced weightlessness inside a parabolic flight – also known as the 'vomit comet'.

"Graphene as we know has a lot of opportunities. One of them, recognised early on, is space applications, and this is the first time that graphene has been tested in space-like applications, worldwide," said Professor Andrea Ferrari, Director of the Cambridge Graphene Centre.

Professor Ferrari is also Science and Technology Officer and Chair of the Management Panel for the Graphene Flagship.

Graphene – the single-atom thick allotrope of carbon – has a unique combination of properties that make it interesting for applications from flexible electronics and fast data communication, to enhanced structural materials and water treatments. It is highly electrically and thermally conductive, as well as strong and flexible.

Credit: University of Cambridge

In this experiment, conducted in November and December last year, the researchers aimed to improve the performance of cooling systems in use in satellites, making use of graphene's excellent thermal properties.

"We are using graphene in what are called loop-heat pipes. These are pumps that move fluid without the need for any mechanical parts, so there is no wear and tear, which is very important for space applications," said Professor Ferrari.

"We are aiming at an increased lifetime and an improved autonomy of the satellites and space probes. By adding graphene, we will have a more reliable loop heat pipe, capable to operate autonomously in space," added Dr. Marco Molina. Dr. Molina is Chief Technical Officer of the Space line of business at Leonardo, an industry partner of the experiment.

In a loop-heat pipe, evaporation and condensation of a fluid is used to transport heat from hot electronic systems out into space. The pressure of the evaporation-condensation cycle forces fluid through the closed systems, providing continuous cooling.

The main element of the loop-heat pipe is the metallic wick, where the fluid is evaporated into gas. In these experiments, the metallic wick was coated in graphene providing two benefits improving efficiency of the heat pipe. Firstly, graphene's excellent thermal properties improve the heat transfer from the hot systems into the wick. Secondly, the porous structure of the graphene coating increases the interaction of the wick with the fluid, and improves the capillary pressure, meaning the liquid can flow through the wick faster.

Dr Yarjan Samad. Credit: Graphene Flagship

After excellent results in laboratory tests, the graphene-coated wicks were tested in space-like conditions on board a Zero-G parabolic flight. To create weightlessness, the plane undergoes a series of parabolic manoeuvres, creating up to 23 seconds of weightlessness in each manoeuvre.

"It was truly a wonderful experience to feel weightlessness, but also the hyper-gravity moments in the plane. I was very excited but at the same time a bit nervous. I couldn't sleep the night before," said Dr. Yarjan Samad, a Research Associate in the Cambridge Graphene Centre.

In the flight, the graphene-coated wicks again demonstrate excellent performance, with more efficient heat and fluid transfer compared to the untreated wicks. Based on these promising results, the researchers are continuing to develop and optimise the coatings for applications in real space conditions.

"The next step will be to start working on a prototype that could go either on a satellite or on the space station," said Professor Ferrari. [28]

Researchers invent light-emitting nanoantennas

Scientists from ITMO University have developed effective nanoscale light sources based on halide perovskite. Such nanosources are based on subwavelength nanoparticles serving both as emitters and nanoantennas and allow enhancing light emission inherently without additional devices. Moreover, perovskite enables tuning of emission spectra throughout the visible range by varying the composition of the material. This makes the new nanoparticles a promising platform for creating compact optoelectronic devices such as optical chips, light-emitting diodes, or sensors. The results were published in *Nano Letters*.

Nanoscale light sources and nanoantennas have a wide range of applications in several areas, such as ultra-compact pixels, optical detection and telecommunications. However, the fabrication of nanostructure-based devices is complicated since the materials typically used have a limited luminescence efficiency. What is more, single quantum dots or molecules usually emit light non-directionally and weakly. An even more challenging task is placing a nanoscale light source precisely near a nanoantenna.

A research group from ITMO University managed to combine a nanoantenna and a light source in a single nanoparticle. It can generate, enhance and route emission via excited resonant modes coupled with excitons. "We used hybrid perovskite as a material for such nanoantennas," says Ekaterina Tiguntseva, first author of the publication. "Unique features of perovskite enabled us to make nanoantennas from this material. We basically synthesized perovskite films, and then transferred material particles from the film surface to another substrate by means of pulsed laser ablation technique. Compared to alternatives, our method is relatively simple and cost-effective."

While studying the obtained perovskite nanoparticles, the scientists discovered that their emission can be enhanced if its spectra match with the Mie-resonant mode. "Currently, scientists are particularly interested in Mie-resonances related to dielectric and semiconductor nanoparticles," says George Zograf, Engineer at the Laboratory of Hybrid Nanophotonics and Optoelectronics at ITMO University. "Perovskites used in our work are semiconductors with luminescence efficiency much higher than that of many other materials. Our study shows that combination of excitons with Mie resonance in perovskite nanoparticles makes them efficient light sources at room temperature."

In addition, the radiation spectrum of the nanoparticles can be changed by varying the anions in the material. "The structure of the material remains the same, we simply use another component in the synthesis of perovskite films. Therefore, it is not necessary to adjust the method each time. It remains the same, yet the emission color of our nanoparticles changes," says Ekaterina.

The scientists will continue research on light-emitting perovskite nanoantennas using various components for their synthesis. In addition, they are developing new designs of perovskite nanostructures which may improve ultra compact optical devices. [27]

Optical nanoscope images quantum dots

Physicists have developed a technique based on optical microscopy that can be used to create images of atoms on the nanoscale. In particular, the new method allows the imaging of quantum dots in a semiconductor chip. Together with colleagues from the University of Bochum, scientists from the University of Basel reported the findings in the journal *Nature Photonics*.

Conventional optical microscopes cannot be used to image individual molecules and atoms, which measure just fractions of a nanometer across. This has to do with the wave nature of light and the associated laws of physics. According to these laws, a microscope's maximum resolution is equal to half the wavelength of the light used. For example, if you use green light with a wavelength of 500 nanometers, an optical microscope can, at best, distinguish objects at a distance of 250 nanometers.

In recent years, however, scientists have circumvented this resolution limit to generate images of structures measuring just a few nanometers across. To do so, they used lasers of various wavelengths to trigger fluorescence in molecules in part of the substance while suppressing it in the surrounding areas. This allows them to image structures such as dye molecules, which are just a few nanometers in size. The development of this method, stimulated emission depletion (STED) resulted in the Nobel Prize in Chemistry 2014.

Timo Kaldewey, from the University of Basel's Department of Physics and Swiss Nanoscience Institute, has now worked with colleagues at Ruhr-University Bochum (Germany) to develop a similar technique that allows the imaging of nanoscale objects, particularly a quantum mechanical two-level system. The physicists studied what are known as quantum dots, artificial atoms in a semiconductor, which the new method was able to image as bright spots. The scientists excited the atoms with a pulsed laser, which changes its color during each pulse. As a result, the atom's fluorescence is switched on and off.

Whereas the STED method only works by occupying at least four energy levels in response to the laser excitation, the new method from Basel also works with atoms that have just two energy states. Two-state systems of this kind constitute important model systems for quantum mechanics. Unlike STED microscopy, the new method also releases no heat. "This is a huge advantage, as any heat released can destroy the molecules you're examining," explains Richard Warburton. "Our nanoscope is suitable for all objects with two energy levels, such as real atoms, cold molecules, quantum dots, or color centers." [26]

Quantum dot ring lasers emit colored light

Researchers have designed a new type of laser called a quantum dot ring laser that emits red, orange, and green light. The different colors are emitted from different parts of the quantum dot—red from the core, green from the shell, and orange from a combination of both—and can be easily switched by controlling the competition between light emission from the core and the shell.

The researchers, Boris le Feber, Ferry Prins, Eva De Leo, Freddy T. Rabouw, and David J. Norris, at ETH Zurich, Switzerland, have published a paper on the new lasers in a recent issue of *Nano Letters*.

The work demonstrates the interesting effects that are possible with lasers based on quantum dots, which are nanosized crystal spheres made of semiconducting materials. In these lasers, the quantum dots are often coated with shells of a different material. When illuminated, the shells not only emit light of their own, but they also channel photoexcited carriers (excitons) to the cores of the quantum dots, which enhances the laser's core light emission.

In order to make quantum dot lasers that can switch between emitting light from only the cores or only the shells, the researchers designed a special laser cavity, which is the central part of the laser responsible for confining and reflecting light until it becomes highly coherent. Although quantum dot lasers have been widely researched, the effect of the laser cavity on quantum dot laser performance has been largely unexplored until now.

In the new study, the scientists fabricated high-quality laser cavities made of arrays of highly structured quantum dot rings. The resulting lasers exhibit very high cavity quality factors—almost an order of magnitude higher than those of typical quantum dot lasers, which usually have random cavities.

"We were able to demonstrate a simple fabrication approach that led to high-quality ring cavities that allowed us to explore this 'color switching' behavior in a quantum dot laser," Norris, Professor of Materials Engineering at ETH Zurich, told *Phys.org*. "In poor-quality cavities it is unlikely that we would have been able to observe this effect."

The researchers demonstrated that, at low powers, the new lasers emit red light from their cores, whereas at higher powers, they emit green light from the shells. At intermediate powers, the light comes from both the core and shell, and so appears orange. As the researchers explain, it's possible to completely stifle core emission because the core emission takes place on a picosecond timescale, while shell emission occurs on a subpicosecond timescale and so can greatly outpace core emission, as long as the laser power is sufficiently high.

In the future, the unique properties of the quantum dot ring lasers may lead to applications in laser displays, chemical sensing, and other areas. But before these applications can be realized, the researchers plan to further improve the laser's performance.

"We demonstrate the 'color switching' effect in this work, but the color change occurs at very high powers," Norris said. "Further research is required to see if the same effect can occur at more reasonable powers. This would be useful for applications. Fortunately, quantum dots continue to improve (in terms of their performance for lasers), and we can immediately apply these improvements to our devices." [25]

Sensing with a twist: A new kind of optical nanosensor uses torque for signal processing

The world of nanosensors may be physically small, but the demand is large and growing, with little sign of slowing. As electronic devices get smaller, their ability to provide precise, chip-based sensing of dynamic physical properties such as motion become challenging to develop.

An international group of researchers have put a literal twist on this challenge, demonstrating a new nanoscale optomechanical resonator that can detect torsional motion at near state-of-the-art sensitivity. Their resonator, into which they couple light, also demonstrates torsional frequency mixing, a novel ability to impact optical energies using mechanical motions. They report their work this week in the journal Applied Physics Letters.

"With developments of nanotechnology, the ability to measure and control torsional motion at the nanoscale can provide a powerful tool to explore nature," said Jianguo Huang from Xi'an Jiaotong University in China, one of the work's authors. He is also affiliated with the Nanyang Technological University and with the Institute of Microelectronics, A*STAR in Singapore. "We present a novel 'beam-in-cavity' design in which a torsional mechanical resonator is embedded into a racetrack optical cavity, to demonstrate nanoscale torsional motion sensing."

Light has already been used in somewhat similar ways to detect the mechanical flexing or

"breathing" of nanomaterials, typically requiring complex and sensitive coupling to the light source. This new approach is novel not only in its detection of nanoscale torques, but also in its integrated light-coupling design.

Using a silicon-based nanofabrication method, Huang and his team designed the device to allow light to couple directly via an etched grating to a waveguide configuration, called a racetrack cavity, in which the nanoresonator sits.

"As light is coupled into the racetrack cavity through a grating coupler, mechanical torsional motion in the cavity alters the propagation of light and changes [the] power of output light," said Huang. "By detecting the small variation of output light, the torsional motions can be measured."

Beyond just detecting torques on their micron-length lever arms, the resonators can also affect the resulting optical properties of the incident signal. The torsional frequency of the mechanical system mixes with the modulated optical signals.

"The most surprising part is that when we modulate the input light, we can observe the frequency mixing," Huang said. "It is exciting for frequency mixing since it has only been demonstrated by flexural or breathing modes before. This is the first demonstration of torsional frequency mixing, which may have implications for on-chip RF signal modulation, such as super-heterodyne receivers using optical mechanical resonators."

This is just the start for potential uses of torque-based nanosensors. Theoretically, there are a number of frequency tricks these devices could play for signal processing and sensing applications.

"We will continue to explore unique characters of this torsional optomechanical sensor and try to demonstrate novel phenomena, such as inference of dispersive and dissipative optomechanical coupling hidden behind the sensing," Huang said. "For engineering, magnetic or electrically-sensitive materials can be coated on the surface of torsional beams to sense small variations of physical fields, such as magnetic or electric fields to serve as multifunctional sensors." [24]

First imaging of free nanoparticles in laboratory experiment using a high-intensity laser source

In a joint research project, scientists from the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy (MBI), the Technische Universität Berlin (TU) and the University of Rostock have managed for the first time to image free nanoparticles in a laboratory experiment using a highintensity laser source. Previously, the structural analysis of these extremely small objects via singleshot diffraction was only possible at large-scale research facilities using so-called XUV and x-ray free electron lasers. Their pathbreaking results facilitate the highly-efficient characterisation of the chemical, optical and structural properties of individual nanoparticles and have just been published in Nature Communications. The lead author of the publication is junior researcher Dr Daniela Rupp who carried out the project at TU Berlin and is now starting a junior research group at MBI.

In their experiment, the researchers expanded helium gas through a nozzle that is cooled to extremely low temperature. The helium gas turns into a superfluid state and forms a beam of

freely flying miniscule nanodroplets. "We sent ultra-short XUV pulses onto these tiny droplets and captured snapshots of these objects by recording the scattered laser light on a large-area detector to reconstruct the droplet shape," explains Dr Daniela Rupp.

"Key to the successful experiment were the high-intensity XUV pulses generated in MBI's laser lab that produce detailed scattering patterns with just one single shot," explains Dr Arnaud Rouzée from MBI. "By using the so-called wide-angle mode that provides access to the three-dimensional morphology, we could identify hitherto unobserved shapes of the superfluid droplets," adds Professor Thomas Fennel from MBI and the University of Rostock. The research team's results enable a new class of metrology for analysing the structure and optical properties of small particles. Thanks to state-of-the-art laser light sources, making images of the tiniest pieces of matter is no longer exclusive to the large-scale research facilities. [23]

Single molecular layer and thin silicon beam enable nanolaser operation at room temperature

For the first time, researchers have built a nanolaser that uses only a single molecular layer, placed on a thin silicon beam, which operates at room temperature. The new device, developed by a team of researchers from Arizona State University and Tsinghua University, Beijing, China, could potentially be used to send information between different points on a single computer chip. The lasers also may be useful for other sensing applications in a compact, integrated format.

"This is the first demonstration of room-temperature operation of a nanolaser made of the singlelayer material," said Cun-Zheng Ning, an ASU electrical engineering professor who led the research team. Details of the new laser are published in the July online edition of Nature Nanotechnology.

In addition to Ning, key authors of the article, "Room-temperature Continuous-wave Lasing from Monolayer Molybdenum Ditelluride Integrated with a Silicon Nanobeam Cavity," include Yongzhuo Li, Jianxing Zhang, Dandan Huang from Tsinghua University.

Ning said pivotal to the new development is use of materials that can be laid down in single layers and efficiently amplify light (lasing action). Single layer nanolasers have been developed before, but they all had to be cooled to low temperatures using a cryogen like liquid nitrogen or liquid helium. Being able to operate at room temperatures (~77 F) opens up many possibilities for uses of these new lasers," Ning said.

The joint ASU-Tsinghua research team used a monolayer of molybdenum ditelluride integrated with a silicon nanobeam cavity for their device. By combining molybdenum ditelluride with silicon, which is the bedrock in semiconductor manufacturing and one of the best waveguide materials, the researchers were able to achieve lasing action without cooling, Ning said.

A laser needs two key pieces – a gain medium that produces and amplifies photons, and a cavity that confines or traps photons. While such materials choices are easy for large lasers, they become more difficult at nanometer scales for nanolasers. Nanolasers are smaller than 100th of the thickness of the human hair and are expected to play important roles in future computer chips and a variety of light detection and sensing devices.

The choice of two-dimensional materials and the silicon waveguide enabled the researchers to achieve room temperature operation. Excitons in molybdenum telluride emit in a wavelength that is transparent to silicon, making silicon possible as a waveguide or cavity material. Precise fabrication of the nanobeam cavity with an array of holes etched and the integration of two-dimensional monolayer materials was also key to the project. Excitons in such monolayer materials are 100 times stronger than those in conventional semiconductors, allowing efficient light emission at room temperature.

Because silicon is already used in electronics, especially in computer chips, its use in this application is significant in future applications.

"A laser technology that can also be made on Silicon has been a dream for researchers for decades," said Ning. "This technology will eventually allow people to put both electronics and photonics on the same silicon platform, greatly simplifying manufacture."

Silicon does not emit light efficiently and therefore must be combined with other light emitting materials. Currently, other semiconductors are used, such as Indium phosphide or Indium Garlium Arsenide which are hundreds of times thicker, to bond with silicon for such applications.

The new monolayer materials combined with Silicon eliminate challenges encountered when combining with thicker, dissimilar materials. And, because this non-silicon material is only a single layer thick, it is flexible and less likely to crack under stress, according to Ning.

Looking forward, the team is working on powering their laser with electrical voltage to make the system more compact and easy to use, especially for its intended use on computer chips. [22]

Computer chip technology repurposed for making reflective nanostructures

A team of engineers at Caltech has discovered how to use computer-chip manufacturing technologies to create the kind of reflective materials that make safety vests, running shoes, and road signs appear shiny in the dark.

Those materials owe their shininess to retroreflection, a property that allows them to bounce light directly back to its source from a wide variety of angles. In contrast, a basic flat mirror will not bounce light back to its source if that light is coming from any angle other than straight on.

Retroreflectors' ability to return light to where it came from makes them useful for highlighting objects that need to be seen in dark conditions. For example, if light from a car's headlights shines on the safety vest of a construction worker down the road, the vest's retroreflective strips will bounce that light straight back to the car and into the driver's eyes, making the vest appear to glow.

Retroreflectors have also been used in surveyors' equipment, communications with satellites, and even in experiments to measure the distance of the moon from Earth.

Typically, retroreflectors consist of tiny glass spheres embedded in the surface of reflective paint or in small mirrors shaped like the inner corner of a cube.

The new technology—which was developed by a team led by Caltech's Andrei Faraon, assistant professor of applied physics and materials science in the Division of Engineering and Applied Science—uses surfaces covered by a metamaterial consisting of millions of silicon pillars, each only a few hundred nanometers tall. By adjusting the size of the pillars and the spacing between them, Faraon can manipulate how the surface reflects, refracts, or transmits light. He has already shown that these materials can be tweaked to create flat lenses for focusing light or to create prism-like surfaces that spread the light out into its spectrum. Now, he's discovered that he can build a retroreflector by stacking two layers of the metamaterials atop one another.

In this kind of retroreflector, light first passes through a transparent metamaterial layer (metasurface) and is focused by its tiny pillars onto a single spot on a reflective metamaterial layer. The reflective layer then bounces the light back to the transparent layer, which transmits the light back to its source.

"By placing multiple metasurfaces on top of each other, it is possible to control the flow of light in such a way that was not possible before," Faraon says. "The functionality of a retroreflector cannot be achieved by using a single metasurface."

Since Faraon's metamaterials are created using computer-chip manufacturing technologies, it would be possible to easily integrate them into chips used in optoelectronic devices—electronics that use and control light, he says.

"This could have applications in communicating with remote sensors, drones, satellites, etc.," he adds.

Faraon's research appears in a paper in the June 19, 2017, edition of Nature Photonics; the paper is titled "Planar metasurface retroreflector." Other coauthors are Amir Arbabi, assistant professor of computer and electrical engineering at the University of Massachusetts Amherst; and Caltech electrical engineering graduate students Ehsan Arbabi, Yu Horie, and Seyedeh Mahsa Kamali. [21]

Physicists create nanoscale mirror with only 2000 atoms

Mirrors are the simplest means to manipulate light propagation. Usually, a mirror is a macroscopic object composed of a very large number of atoms. In the September 23th issue of the Physical Review Letters, Prof. Julien Laurat and his team at Pierre and Marie Curie University in Paris (Laboratoire Kastler Brossel-LKB) report that they have realized an efficient mirror consisting of only 2000 atoms. This paper is accompanied by a "Focus" item in APS-Physics.

By engineering the position of cold atoms trapped around a nanoscale fiber, the researchers fulfill the necessary conditions for Bragg reflection, a well-known physical effect first proposed by William Lawrence Bragg and his father William Henry Bragg in crystalline solids. They earned the Nobel Prize for this work in 1915.

In the current experiment, each trapped atom contributes with a small reflectance, and the engineered position allows the constructive interference of multiple reflections.

"Only 2000 atoms trapped in the vicinity of the fiber were necessary, while previous demonstrations in free space required tens of millions of atoms to get the same reflectance," says

Neil Corzo, a Marie-Curie postdoctoral fellow and the lead author of this work. He adds, "This is due to the strong atom-photon coupling and the atom position control that we can now achieve in our system."

The key ingredient is a nanoscale fiber, whose diameter has been reduced to 400 nm. In this case, a large fraction of the light travels outside the fiber in an evanescent field where it is heavily focused over the 1-cm nanofiber length. Using this strong transversal confinement, it is possible to trap cold cesium atoms near the fiber in well-defined chains. The trapping is made with the implementation of an all-fibered dipole trap. With the use of well-chosen pairs of beams, the researchers generate two chains of trapping potentials around the fiber, in which only one atom occupies each site. By selecting the correct colors of the trap beams, they engineered the distance between atoms in the chains to be close to half the resonant wavelength of the cesium atoms, fulfilling the necessary conditions for Bragg reflection.

This setting represents an important step in the emerging field of waveguide quantum electrodynamics, with applications in quantum networks, quantum nonlinear optics, and quantum simulation. The technique would allow for novel quantum network capabilities and many-body effects emerging from long-range interactions between multiple spins, a daunting prospect in free space.

This demonstration follows other works that Laurat's group has done in recent years, including the realization of an all-fibered optical memory. [20]

For first time, researchers see individual atoms keep away from each other or bunch up as pairs

If you bottle up a gas and try to image its atoms using today's most powerful microscopes, you will see little more than a shadowy blur. Atoms zip around at lightning speeds and are difficult to pin down at ambient temperatures.

If, however, these atoms are plunged to ultracold temperatures, they slow to a crawl, and scientists can start to study how they can form exotic states of matter, such as superfluids, superconductors, and quantum magnets.

Physicists at MIT have now cooled a gas of potassium atoms to several nanokelvins—just a hair above absolute zero—and trapped the atoms within a two-dimensional sheet of an optical lattice created by crisscrossing lasers. Using a high-resolution microscope, the researchers took images of the cooled atoms residing in the lattice.

By looking at correlations between the atoms' positions in hundreds of such images, the team observed individual atoms interacting in some rather peculiar ways, based on their position in the lattice. Some atoms exhibited "antisocial" behavior and kept away from each other, while some bunched together with alternating magnetic orientations. Others appeared to piggyback on each other, creating pairs of atoms next to empty spaces, or holes.

The team believes that these spatial correlations may shed light on the origins of superconducting behavior. Superconductors are remarkable materials in which electrons pair up and travel without

friction, meaning that no energy is lost in the journey. If superconductors can be designed to exist at room temperature, they could initiate an entirely new, incredibly efficient era for anything that relies on electrical power.

Martin Zwierlein, professor of physics and principal investigator at MIT's NSF Center for Ultracold Atoms and at its Research Laboratory of Electronics, says his team's results and experimental setup can help scientists identify ideal conditions for inducing superconductivity.

"Learning from this atomic model, we can understand what's really going on in these superconductors, and what one should do to make higher-temperature superconductors, approaching hopefully room temperature," Zwierlein says.

Zwierlein and his colleagues' results appear in the Sept. 16 issue of the journal Science. Co-authors include experimentalists from the MIT-Harvard Center for Ultracold Atoms, MIT's Research Laboratory of Electronics, and two theory groups from San Jose State University, Ohio State University, the University of Rio de Janeiro, and Penn State University.

"Atoms as stand-ins for electrons"

Today, it is impossible to model the behavior of high-temperature superconductors, even using the most powerful computers in the world, as the interactions between electrons are very strong. Zwierlein and his team sought instead to design a "quantum simulator," using atoms in a gas as stand-ins for electrons in a superconducting solid.

The group based its rationale on several historical lines of reasoning: First, in 1925 Austrian physicist Wolfgang Pauli formulated what is now called the Pauli exclusion principle, which states that no two electrons may occupy the same quantum state—such as spin, or position—at the same time. Pauli also postulated that electrons maintain a certain sphere of personal space, known as the "Pauli hole."

His theory turned out to explain the periodic table of elements: Different configurations of electrons give rise to specific elements, making carbon atoms, for instance, distinct from hydrogen atoms.

The Italian physicist Enrico Fermi soon realized that this same principle could be applied not just to electrons, but also to atoms in a gas: The extent to which atoms like to keep to themselves can define the properties, such as compressibility, of a gas.

"He also realized these gases at low temperatures would behave in peculiar ways," Zwierlein says.

British physicist John Hubbard then incorporated Pauli's principle in a theory that is now known as the Fermi-Hubbard model, which is the simplest model of interacting atoms, hopping across a lattice. Today, the model is thought to explain the basis for superconductivity. And while theorists have been able to use the model to calculate the behavior of superconducting electrons, they have only been able to do so in situations where the electrons interact weakly with each other.

"That's a big reason why we don't understand high-temperature superconductors, where the electrons are very strongly interacting," Zwierlein says. "There's no classical computer in the world that can calculate what will happen at very low temperatures to interacting [electrons]. Their

spatial correlations have also never been observed in situ, because no one has a microscope to look at every single electron."

Carving out personal space

Zwierlein's team sought to design an experiment to realize the Fermi-Hubbard model with atoms, in hopes of seeing behavior of ultracold atoms analogous to that of electrons in high-temperature superconductors.

The group had previously designed an experimental protocol to first cool a gas of atoms to near absolute zero, then trap them in a two-dimensional plane of a laser-generated lattice. At such ultracold temperatures, the atoms slowed down enough for researchers to capture them in images for the first time, as they interacted across the lattice.

At the edges of the lattice, where the gas was more dilute, the researchers observed atoms forming Pauli holes, maintaining a certain amount of personal space within the lattice.

"They carve out a little space for themselves where it's very unlikely to find a second guy inside that space," Zwierlein says.

Where the gas was more compressed, the team observed something unexpected: Atoms were more amenable to having close neighbors, and were in fact very tightly bunched. These atoms exhibited alternating magnetic orientations.

"These are beautiful, antiferromagnetic correlations, with a checkerboard pattern—up, down, up, down," Zwierlein describes.

At the same time, these atoms were found to often hop on top of one another, creating a pair of atoms next to an empty lattice square. This, Zwierlein says, is reminiscent of a mechanism proposed for high-temperature superconductivity, in which electron pairs resonating between adjacent lattice sites can zip through the material without friction if there is just the right amount of empty space to let them through.

Ultimately, he says the team's experiments in gases can help scientists identify ideal conditions for superconductivity to arise in solids.

Zwierlein explains: "For us, these effects occur at nanokelvin because we are working with dilute atomic gases. If you have a dense piece of matter, these same effects may well happen at room temperature."

Currently, the team has been able to achieve ultracold temperatures in gases that are equivalent to hundreds of kelvins in solids. To induce superconductivity, Zwierlein says the group will have to cool their gases by another factor of five or so.

"We haven't played all of our tricks yet, so we think we can get colder," he says. [19]

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

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

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

In their new work, the researchers bested themselves by increasing this factor to 32 (15 dB of squeezing), using a light-squeezing scheme with low optical losses and minimal fluctuations in the phase of the readout scheme. The squeezed states are obtained at 1064 nm, the laser wavelength feeding the interferometers of all current GW observatories.

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

Liquid Light with a Whirl

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

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

The idea that light can behave like a fluid and, even more interestingly, a superfluid (a fluid with zero viscosity), goes back at least to the 1990s. The analogy comes about because Maxwell’s equations for nearly collimated light in a nonlinear medium look like the Schrödinger equation for a superfluid of matter, modified to include particle interactions. Fluids of light, or photon fluids,

propagating in bulk nonlinear media show a range of fluid and superfluid behavior, such as free expansion and shock waves. In microcavities, fluids of light can be strongly coupled to matter, such as semiconductor electron-hole pairs, to make hybrid entities known as polariton condensates. These condensates can exhibit quantized vortices, which are characteristic of superfluidity. Despite these impressive advances, it has proven difficult to induce the strong bulk rotation required for phenomena such as the quantum Hall effect to show up in photon fluids, hence the need for synthetic magnetism.

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

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

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

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

The authors present numerical simulations for both types of nonlinearity. For the second-order nonlinear medium, they show that an elliptical light beam in a synthetic magnetic field rotates about its propagation axis and expands as it propagates (Fig 1). The expansion shows that the light is behaving as a fluid in rotation. For the third-order nonlinear medium there is a trapped vortex that causes the beam to rotate, which is akin to cyclotron motion of a charge in a magnetic field.

Short of spinning the medium extremely rapidly [9], it is not obvious how one could otherwise make a beam continuously rotate as it propagates.

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

Physicists discover a new form of light

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

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

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

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

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

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

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

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

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

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

Novel metasurface revolutionizes ubiquitous scientific tool

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

While other technologies have been applied to frequency conversion, "nanophotonics has the benefit of potentially enabling the devices to be much smaller, easier to customize, lower power, and compatible with batch fabrication technology," said Srinivasan. "Our work is a first

demonstration of a nanophotonic technology suitable for this demanding task of quantum frequency conversion." [14]

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

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

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

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

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

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

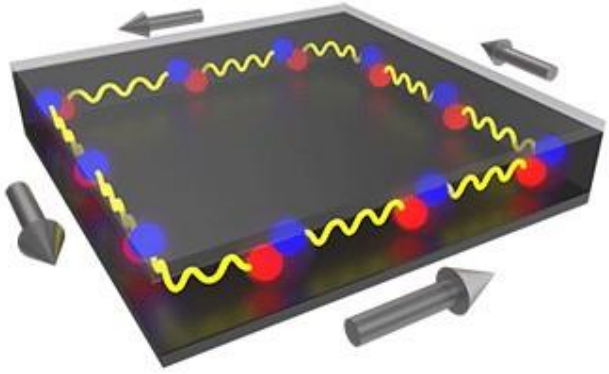
The researchers found that the rate for non-radiative energy transfer from individual quantum dots to tin disulfide increases with an increasing number of tin disulfide layers. But performance in laboratory tests isn't enough to prove the merits of potential new materials. So the scientists incorporated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

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

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

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

Quasiparticles dubbed topological polaritons make their debut in the theoretical world



Condensed-matter physicists often turn to particle-like entities called quasiparticles—such as excitons, plasmons, magnons—to explain complex phenomena. Now Gil Refael from the California Institute of Technology in Pasadena and colleagues report the theoretical concept of the topological 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) $I = I_0 \sin^2 n\,\varphi/2 \,/\, \sin^2 \varphi/2$

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

(2) $\iota = n^2 \iota_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

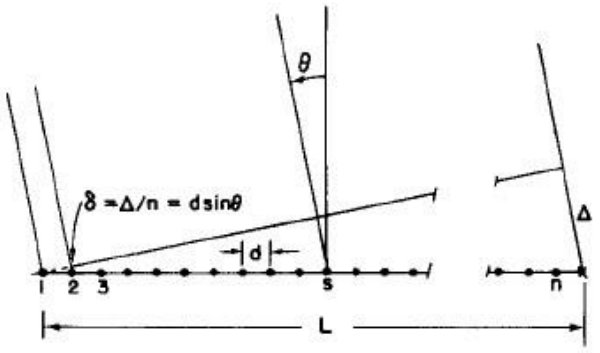


Fig. 30–3. A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.

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 θ = m λ 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 θ = 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:

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

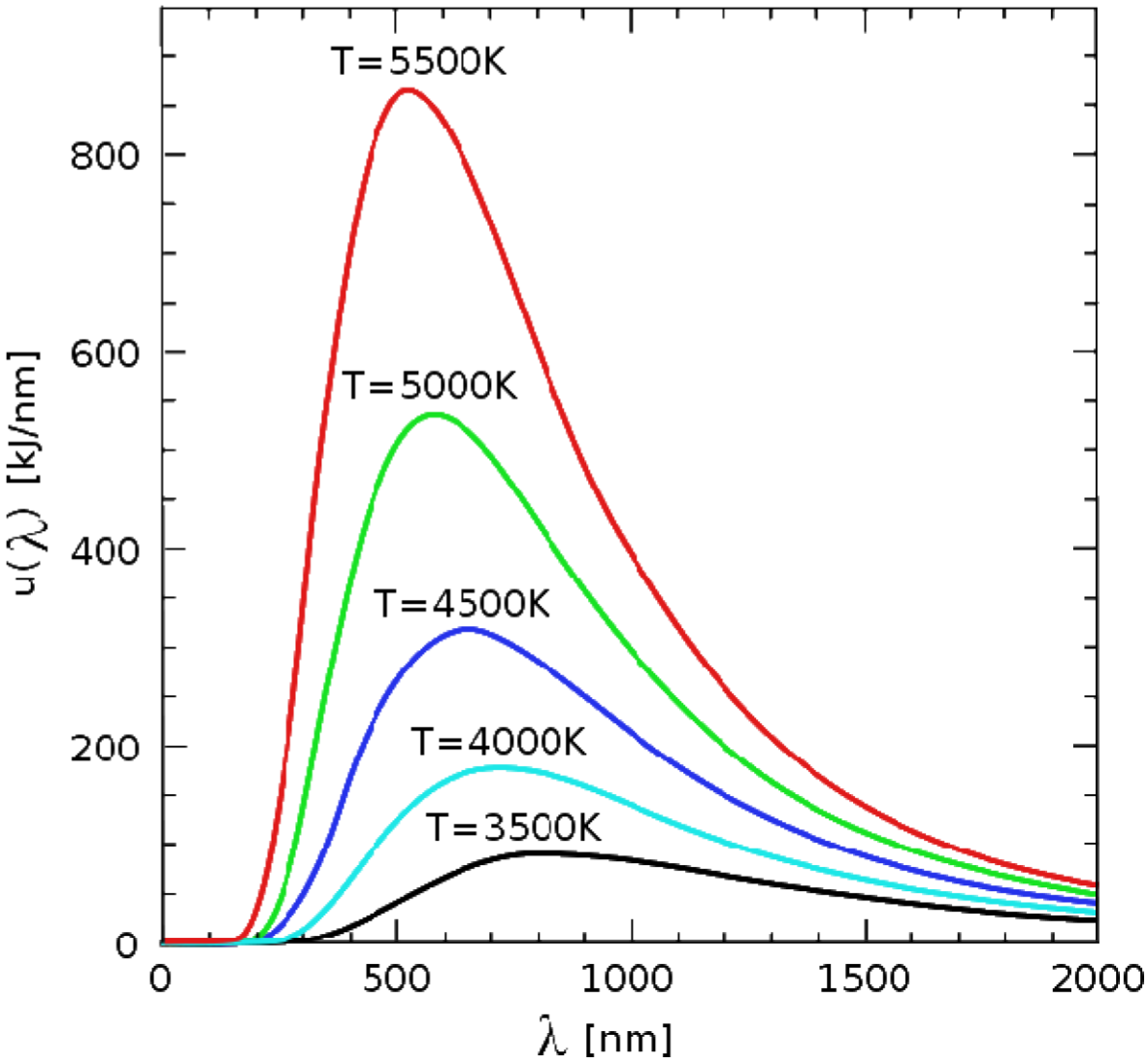


Figure 2. The distribution law for different T temperatures

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 onedimensional (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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