Passivation of Perovskite Photovoltaics

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Hybrid organic or inorganic halide perovskites are a unique class of solar cell materials that break some of the material design rules that have been in place for over 30 years. [19]

Efficient near-infrared (NIR) light-emitting diodes of perovskite have been produced in a laboratory at Linköping University. The external quantum efficiency is 21.6 percent, which is a record. The results have been published in Nature Photonics. [18]

Very recently, an NTU team lead by Assoc. Prof. Wang Hong, demonstrated high light extraction efficiency of perovskite photonic crystals fabricated by delicate electron-beam lithography. [17]

A quasiparticle is a disturbance or excitation (e.g. spin waves, bubbles, etc.) that behaves as a particle and could therefore be regarded as one. Long-range interactions between quasiparticles can give rise to a 'drag,' which affects the fundamental properties of many systems in condensed matter physics. [16]

Researchers have recently been also interested in the utilization of antiferromagnets, which are materials without macroscopic magnetization but with a staggered orientation of their microscopic magnetic moments. [15]

A new method that precisely measures the mysterious behavior and magnetic properties of electrons flowing across the surface of quantum materials could open a path to next-generation electronics. [14]

The emerging field of spintronics aims to exploit the spin of the electron. [13]

In a new study, researchers measure the spin properties of electronic states produced in singlet fission – a process which could have a central role in the future development of solar cells. [12]

In some chemical reactions both electrons and protons move together. When they transfer, they can move concertedly or in separate steps. Light-induced reactions of this sort are particularly relevant to biological systems, such as Photosystem II where plants use photons from the sun to convert water into oxygen. [11]

EPFL researchers have found that water molecules are 10,000 times more sensitive to ions than previously thought. [10]

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

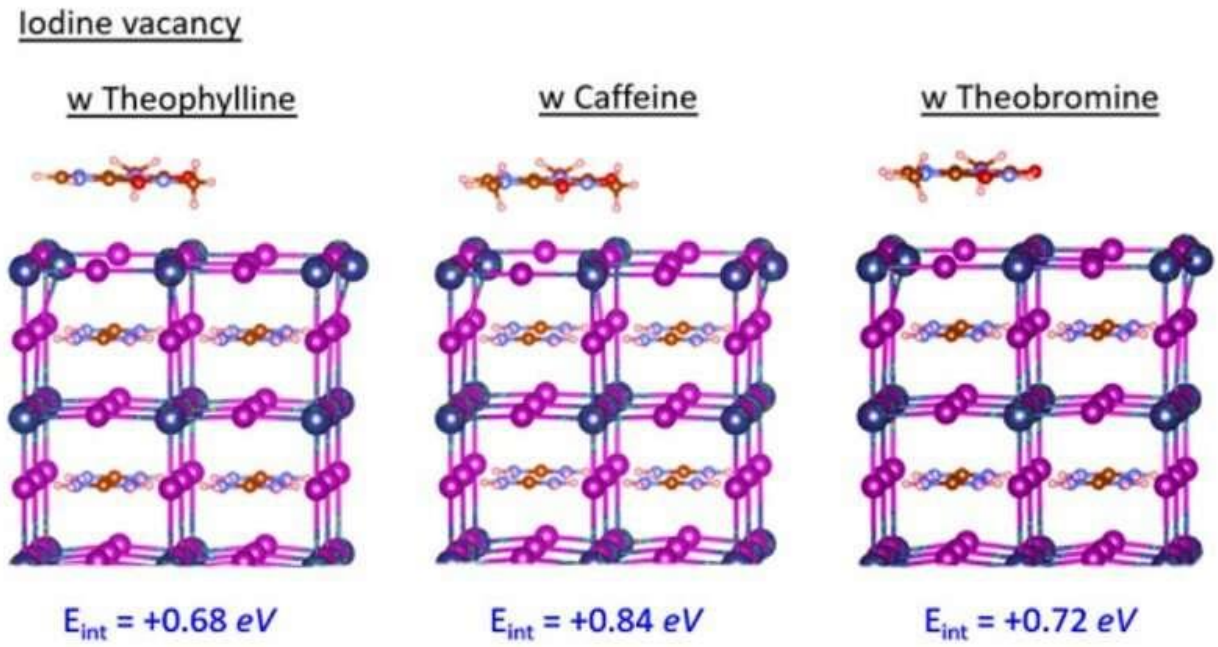
Constructive molecular configurations for surface-defect passivation of perovskite photovoltaics

Materials scientists aim to enable surface-trap-mediated nonradiative charge recombination to engineer highly efficient metal-halide perovskite photovoltaics (solar cells). Since unproductive charge recombination at surface defects can limit the efficiency of hybrid perovskite solar cells, scientists can passivate the defects (induce an acid-base chemical treatment) using small molecular binding. The ionic character of perovskite lattice can allow

molecular defect passivation through interactions between functional groups and surface defects. However, there exists a lack of in-depth understanding on how molecular configurations can influence passivation effectiveness to facilitate rational molecular design.

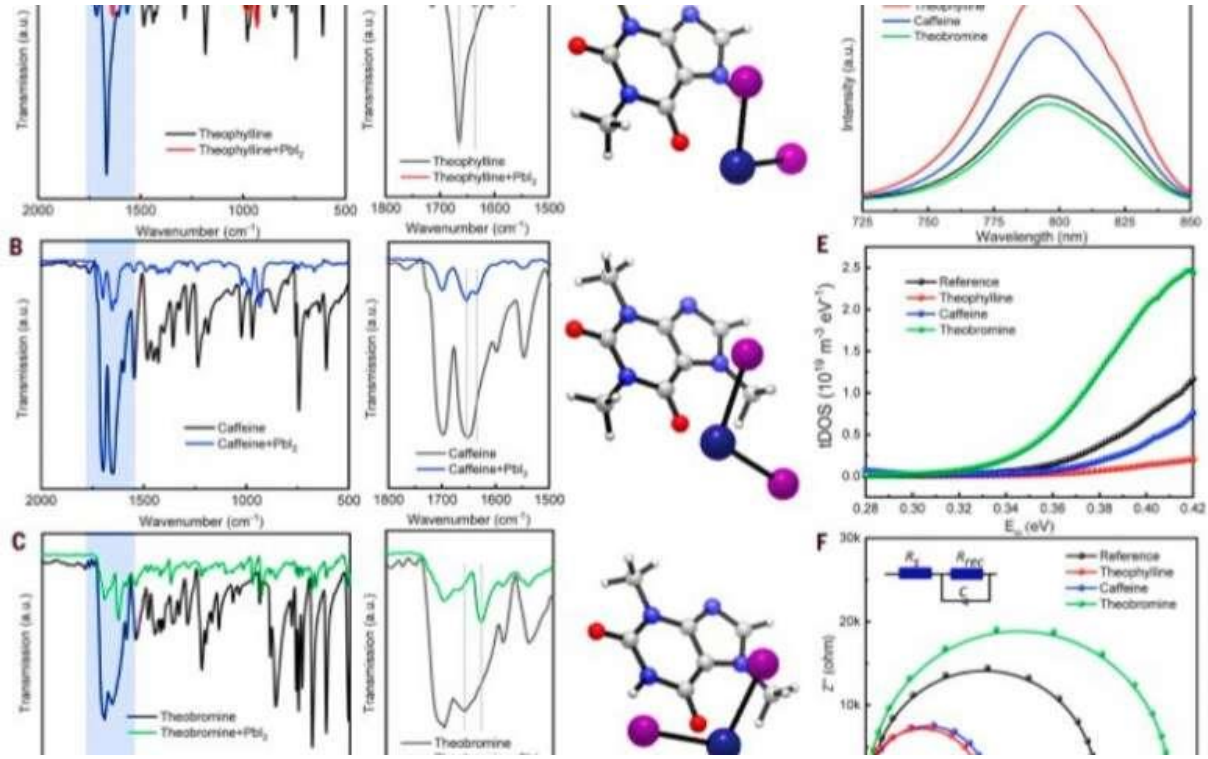
In a new report on *Science*, Rui Wang and an interdisciplinary research team in the departments of Physics, Materials Science & Engineering, Nanoengineering, Chemistry & Biochemistry and the Institute of Functional Nano & Soft Materials in the U.S. and China, investigated the chemical environment of a functional group activated for defect passivation. They conducted experiments to achieve enhanced power conversion efficiencies for perovskite photovoltaics using theophylline, caffeine and theobromine compounds bearing carbonyl (C=O) and amino groups (N-H). In theophylline treated experiments, hydrogen bonding of the amino hydrogen to surface iodide optimized the carbonyl interaction with a lead (Pb) antisite defect to improve the efficiency of a perovskite cell from 21 to 22.6 percent.

Materials scientists implement defect passivation as an important strategy to reduce unproductive charge recombination and increase power conversion efficiency (PCE) of polycrystalline metal-halide perovskite thin-film photovoltaics for solar cells. Based on Lewis acid-base chemistry, the ionic nature of the perovskite lattice can facilitate molecular passivation through coordinate binding. Based on molecular design rules, scientists can select molecules with optimal binding configurations for such surface defect passivation activities. In this work, Wang et al. demonstrated high efficiencies for perovskite (PV) devices via defect identification and conducted rational design and extensive investigations of the chemical environment surrounding the active functional group for defect passivation. In high-quality perovskite polycrystalline thin films with monolayered grains, the interior defects were negligible compared with surface defects.



The DFT-D3 predicted interaction energies between the molecule and slab complex for the VI (Iodine vacancy) case. Credit: Science, doi: 10.1126/science.aay9698

The research team used density functional theory (DFT) calculations to compare formation energies of selected native defects on the perovskite surface. Since band edges of the perovskites are composed of lead (Pb) and Iodine (I) orbitals, Wang et al. specifically investigated Pb and I-involving point defects, Pb vacancy (V_{Pb}), I vacancy (V_I) and Pb-I antisite defects. Using X-ray photoelectron spectroscopy (XPS), the research team confirmed the surface of as-fabricated perovskite thin film to be synthesized in a two-step method to be Pb-rich. Then using the top-layer view of atomic structures, they studied surface defects, followed by the dispersion correction 3 (DFT-D3) method to calculate defect formation energies (DFE). Based on the results, the research team focused on the interaction between the surface Pb and antisite defect to consider candidate molecules for defect passivation. For this, they chose a small set of molecules that shared identical functional groups, although with strategically varying chemical structures to include theophylline, caffeine and theobromine, to interact with the defects.

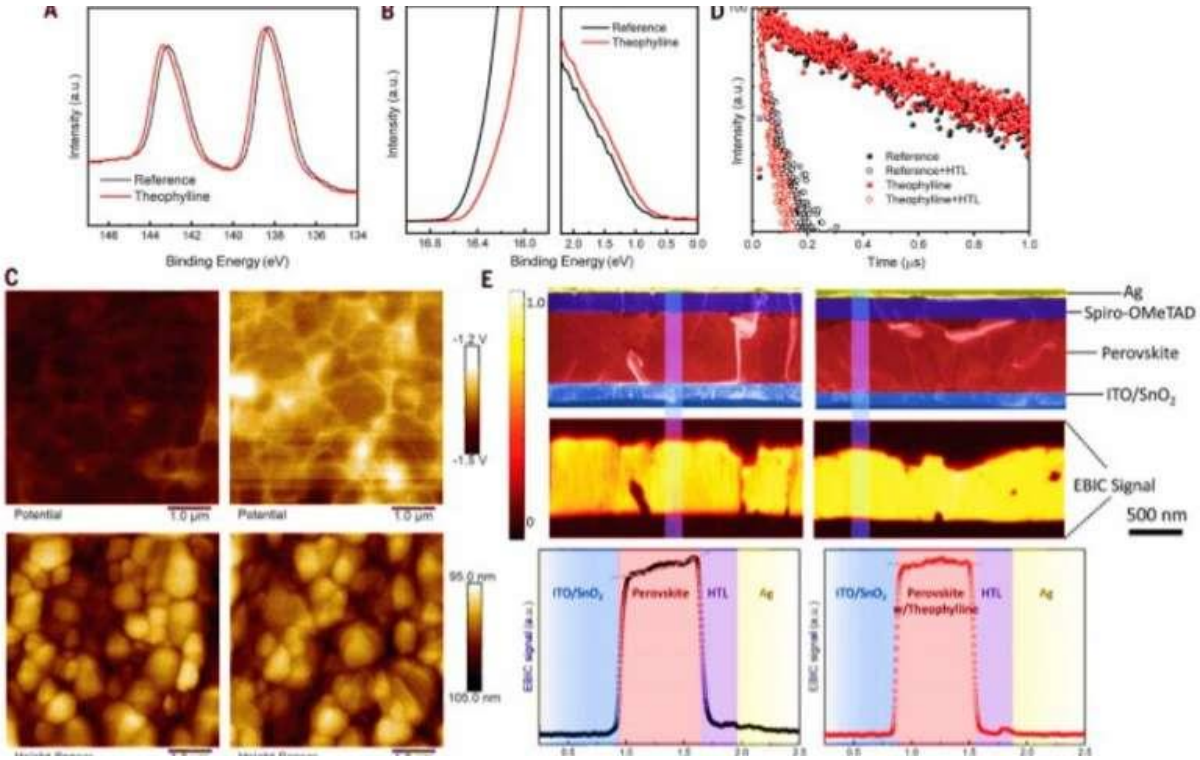


Investigation of the interactions between surface defects and the small molecules. FTIR spectra of (A) pure theophylline and theophylline-PbI2 films, (B)pure caffeine and caffeine-PbI2 films, and (C)pure theobromine and theobromine-PbI2 films. (D) PL spectra of perovskite films without and with small-molecules treatment. (E) tDOS in perovskite solar cells with or without small molecules treatment. (F) Nyquist plots of perovskite solar cells with or without small-molecules treatment measured in the dark and at corresponding open-circuit voltages. a.u., arbitrary units; C, junction capacitance; Rrec, recombination resistance; Rs, Series Resistance. Credit: Science, doi: 10.1126/science.aay9698

These molecules are typically found in natural products such as tea, coffee and chocolate, and are therefore readily accessible. The molecules were also nonvolatile in nature, rendering them suitable for interactions with defects in perovskite for long-term device stability. Wang et al. incorporated theophylline onto the surface of a perovskite thin film via a post-treatment technique to enhance the PCE (power conversion efficiency) from 21 percent to 23 percent in the PV devices. They tested the current density-voltage curves of the PV devices with and without theophylline treatment and credited enhanced open-circuit voltage (V_{OC}) to surface passivation by theophylline due to Lewis base-acid interactions between the C=O group on theophylline and the antisite Pb surface defects. They then compared the results of a theophylline-treated device to a caffeine-treated perovskite PV device.

Subsequently, Wang et al. located the N-H group next to the C=O (carbonyl) group on the same six-membered ring in theobromine to produce a shorter distance between the two groups, followed by disabling spatially effective interactions to form an even weaker interaction energy (E_{int}) of -1.1 eV. The results emphasized the importance of constructive configuration of N-H and C=O groups to allow cooperative multisite interactions and allow synergistic passivation effect to form efficient and stable perovskites. Wang et al. studied the variation in the C=O and PbI_2-terminated perovskite surface interaction with different configurations using Fourier-transform infrared (FTIR)

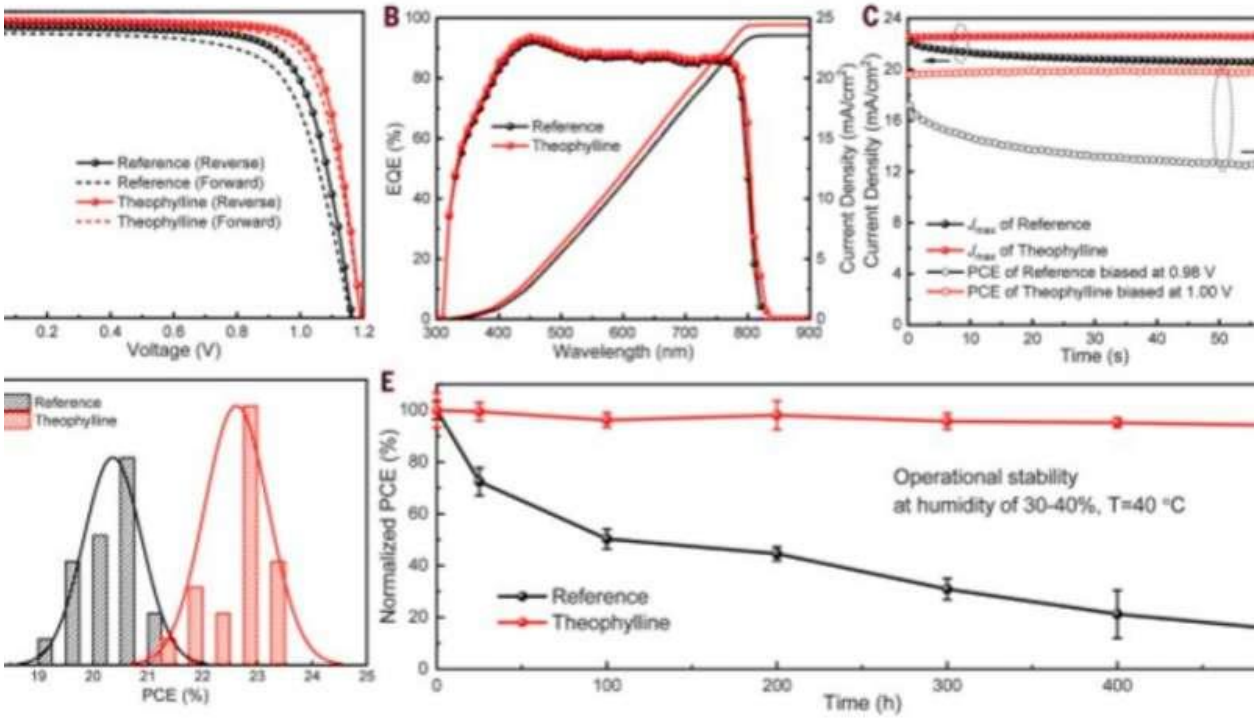
spectroscopy. They examined surface passivation effects of the three molecules using different configurations with photoluminescence (PL) and observed PL intensity to noticeably increase after theophylline treatment. They also observed enhanced PL intensity after caffeine treatment, which was not as strong as theophylline and decreased PL intensity for theobromine compared with the reference material; they credited this to the destructive molecular configuration of passivation agents to produce increased charge recombination sites.



Characterization of perovskite films and interfaces with theophylline treatment. (A) XPS data for Pb 4f 7/2 and Pb 4f 5/2 core-level spectra in perovskite films with or without theophylline treatment. (B) UPS spectra of perovskite films with or without theophylline treatment. (C) AFM and KPFM images of perovskite films with (right) or without (left) theophylline treatment. (D) Time-resolved PL spectra of perovskite films before and after depositing Spiro-OMeTAD without and with theophylline treatment. (E) Cross-section SEM images and the corresponding EBIC images and line profile of the perovskite solar cells with (right) or without (left) theophylline treatment. Credit: Science, doi: 10.1126/science.aay9698

The scientists then deduced trap density of states (tDOS), i.e., the number of states occupied in the system, within as-fabricated devices via angular frequency-dependent capacitance as a function of the defect energy. The results demonstrated a reduction in trap states for theophylline and caffeine-treated perovskite devices compared with the reference material. In contrast, theobromine treatment induced more trap states, consistent with the observed decrease in PCE. Wang et al. confirmed the change in tDOS with different surface treatments using theoretical modelling and conducted electrochemical impedance spectroscopy (EIS) characterization to understand carrier transport processes under illumination at the interface.

The device with theophylline surface treatment had the smallest impedance; signifying a substantially suppressed charge recombination at the interface, originating from reduced surface defect states. The caffeine-treated devices recorded a larger impedance while theobromine-treated devices demonstrated an even larger impedance. To understand perovskite interface treated with theophylline, the scientists conducted further characterizations using ultraviolet photoelectron spectroscopy (UPS) to measure the surface band structure. Followed by atomic force microscopy (AFM) combined with Kelvin probe force microscopy (KPFM) to understand the influence of theophylline on surface morphology and surface potential. The theophylline-treated surfaces exhibited higher electronic chemical potential compared to the reference film while retaining the unchanged surface morphology.



Enhanced photovoltaic performance and long-term stability of perovskite solar cells with theophylline treatment. (A) J-V curves of perovskite solar cells with or without theophylline treatment. (B) EQE curves of perovskite solar cells with or without theophylline treatment. (C) Stabilized maximum power output and the photocurrent density at maximum power point as a function of time for the best-performing perovskite solar cells with or without theophylline treatment, as shown in (A), recorded under simulated 1-sun AM1.5G illumination. (D) PCE distribution of perovskite solar cells with or without theophylline treatment. (E) Evolution of the PCEs measured from the encapsulated perovskite solar cells with or without theophylline treatment exposed to continuous light (90±10mWcm−2) under open-circuit condition. Credit: Science, doi: 10.1126/science.aay9698

The perovskite film showed a slightly long carrier lifetime after theophylline treatment while observing a faster decay profile upon adding a hole-transporting layer on top of the film to reduce recombination and increase absorption properties. The improved carrier dynamics originated due to effective surface passivation with theophylline. When Wang et al. further characterized the surface using

cross-sectional electron-beam-induced current (EBIC) measurements; theophylline treated devices exhibited higher EBIC current compared with the reference device to indicate enhanced carrier collection efficiency.

Theophylline treatment also allowed for minimal decay in the perovskite layers to result in fewer surface recombination sites and showed negligible hysteresis (microscopic surface defects). The enhanced shelf-stability of theophylline-treated devices could maintain >95 percent of its original PCE upon storage under ambient conditions of humidity for 60 days. In this way, Rui Wang and colleagues achieved stable power conversion efficiency for PV devices after incorporating theophylline for long-term operational stability. [20]

Study unveils new spatiotemporal dynamics of carriers in perovskite thin films

Hybrid organic or inorganic halide perovskites are a unique class of solar cell materials that break some of the material design rules that have been in place for over 30 years. For instance, they can achieve an extraordinarily high performance, despite being rich in defects and disordered on a macroscopic scale.

This disordered quality is in stark contrast with the more traditional inorganic semiconductors that are currently used to fabricate electronics. In addition, their morphology makes it far harder to quantify spatial transport parameters that are essential for optimizing the structures of devices.

The performance of semiconductor devices is fundamentally governed by charge-carrier dynamics within the materials. While many researchers have tried to gain a better understanding of these dynamics, many questions remain unanswered.

For instance, the ballistic transport of charge carriers (e.g., electrons) through these materials, also known as ballistic propagation, was so far thought to play no relevant role in enabling the functioning of photovoltaics (PVs) and light-emitting diodes. This is because this propagation is quickly disrupted after the carriers are generated, via a process known as scattering.

A team of researchers at the University of Cambridge and the University of Oxford have recently carried out a study aimed at discovering more about the charge-carrier dynamics in perovskite materials. Their study, published in *Nature Physics*, specifically investigated the spatiotemporal dynamics of carriers immediately after photons are absorbed by methylammonium lead iodide perovskite films.

"Interestingly, hybrid organic-inorganic halide perovskites materials also display rich ultrafast dynamics on the sub-200 fs time scale, which has remained largely unexplored till now," the researchers told Phys.org, via email. "We therefore sought a direct probe to visualize the photoinduced charge carrier transport behaviour in these materials on the femtosecond time scale coupled with nanometer spatial precision."

To investigate the spatiotemporal dynamics of carriers in methylammonium lead iodide perovskite films, the researchers used a time-resolved optical microscope with extreme temporal resolution and nanometer spatial precision. They used a highly spatially confined pump beam on the order of 200 nm to excite the material, which resulted in the generation of excited electrons only within a small area of their sample.

"By delivering a loosely focused probe beam onto the material and varying the time delay with respect to the pump beam, the spatial dynamics of the photogenerated electron distribution can be recorded," the researchers explained. "Since we are comparing the changes in the distribution over time, the spatial precision is not limited by the optical diffraction limit but by the measurement precision."

The spatial precision achieved by their optical microscope allowed the researchers to distinguish dynamics on lengthscales as small as a ten nanometers within the material. Using this time-resolved optical microscopy technique, the researchers could directly visualize the motion of electrons, even within a few tens of femtoseconds.

Their study gathered the first imaging data clearly showing the functioning of perovskite materials directly after photon absorption. They found that immediately after photons are absorbed, electrons in these materials move extremely quickly over an unprecedented distance.

"After recording the movie of photoexcited electrons, we quantified the width of the electron distribution at each snapshot and recorded the mean squared displacement," the researchers said. "This analysis provides the mobility of electrons."

The researchers observed that electrons moved at a velocity of 5×10^6 m s^{-1} over 150 nm, which is almost 1 percent of the speed of light over 150 nm. This enormous speed implies that in halide perovskites electrons move in a wave-like manner, as described by theories in quantum mechanics predicting wave-particle duality.

"This is a very surprising result, as it has long been assumed that the quantum mechanical behavior of electrons breaks down very quickly in solar cells and gives way 'classical' behavior," the researchers said.

The observations could have important implications for the development of new technologies, as they ultimately call for a re-evaluation of current theories on how solar cells work, both those made of perovskites and those fabricated using other inorganic semiconductors. In fact, contrary to most previous studies, these findings suggest that quantum behavior is present in most operating solar cells.

"Now that we have discovered this unprecedented transport regime, we will start looking at other materials to see if there is a universal design rule that dictates the appearance of ballistic transport," the researchers said. "If we can establish such an universal connection, it might well prove to be transformative in the way we think about designing solar cells in the future." [19]

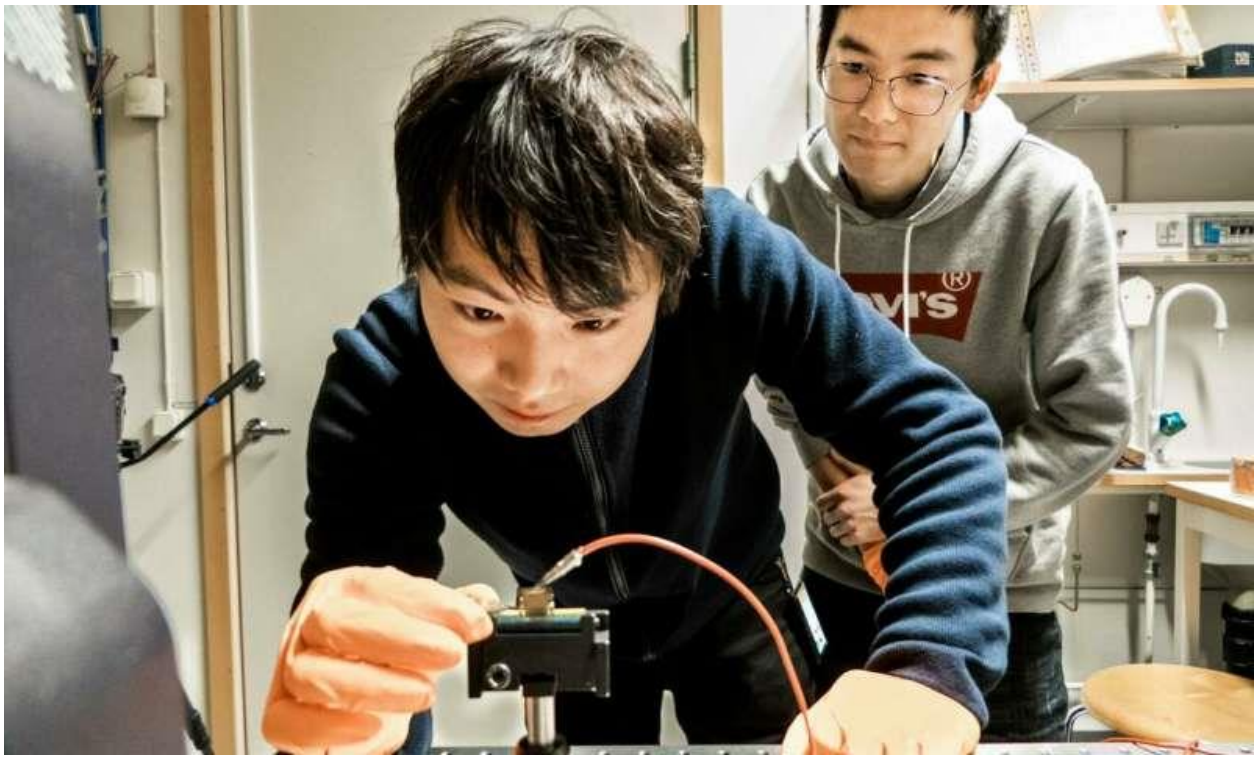
Record efficiency for perovskite-based light-emitting diodes

Efficient near-infrared (NIR) light-emitting diodes of perovskite have been produced in a laboratory at Linköping University. The external quantum efficiency is 21.6 percent, which is a record. The results have been published in *Nature Photonics*.

The work is led by LiU scientist Feng Gao, in close collaboration with colleagues in China, Italy, Singapore and Switzerland.

Perovskites are a group of materials defined by their crystal structure, and have been the focus of intense research interest during the past 10 years, initially for solar cells and recently also for light emitting diodes. They have good light-emitting properties and are easy to manufacture. The external quantum efficiency (the ratio of charge carriers emitted as light over all of those fed into the materials) of light-emitting diodes based on perovskites has until now been limited by defects that arise in the material during manufacture. The defects act as traps for the charge carriers and thus cause energy losses.

One way of dealing with defects is to add materials known as "passivation molecules," which bind to the atoms that cause defects. The researchers had previously discovered a molecule with amino groups at its ends that gave a certain improvement in properties. However, when they selected a molecule that also contained oxygen atoms, the effect increased dramatically.



Weidong Xu in the laboratory at Linköping University. Credit: Thor Balkhed

"We now understand that it is the hydrogen bonds between passivation molecules and perovskite materials that cause problems. This allowed us to search for a molecule that was perfect for passivation," says Feng Gao, senior lecturer in the Division of Biomolecular and Organic Electronics at Linköping University.

The molecule they found has two amino groups at its ends, with oxygen atoms at suitable distances between them. Oxygen atoms reduce the hydrogen bonding ability of amino groups, and hence increase the probability that they interact with defects. The number of traps for charge carriers in the perovskite is significantly reduced, allowing the charge carriers to recombine and emit light efficiently.

"This particular perovskite material gives highly efficient light-emitting diodes in the near-infrared region. Near-infrared light-emitting diodes are particularly useful for medical and telecommunication applications. We believe that our new findings can also be applied to perovskite light-emitting diodes with other colours," says Feng Gao.

The external quantum efficiency is a record-high 21.6 percent.

"We have developed the best light-emitting diodes in perovskite material yet. They can also compete with light-emitting diodes based on, for example, organic materials," says Wiedong Xu, postdoc in the Division of Biomolecular and Organic Electronics, LiU. [18]

Brightening perovskite LEDs with photonic crystals

All inorganic cesium lead halide perovskite semiconductors exhibit great potential for nanolasers, light emitting diodes and solar cells due to their unique properties, including low threshold, high quantum efficiency and low cost. However, the high material refractive index of perovskite semiconductors hinders light extraction efficiency for photonic and illumination applications.

Very recently, an NTU team lead by Assoc. Prof. Wang Hong, demonstrated high lightextraction efficiency of perovskite photonic crystals fabricated by delicate electron-beam lithography. The perovskite photonic crystals exhibit both emission rate inhibition and light energy redistribution simultaneously.

They observed 7.9-fold reduction of the spontaneous emission rate with a slower decay in perovskite photonic crystals due to the photonic bandgap effect (PBG). 23.5-fold emission intensity enhancement was also clearly observed as a result of light energy redistribution from 2-D guided modes to vertical direction in perovskite photonic crystals thin films, indicating a high intrinsic light extraction efficiency.

This observation is the second largest extraction efficiency with two-dimensional photonic crystals in comparison with that of silicon. There is an emission inhibition, but since the light is improved by the direction coupling, the emission image in Fig. 1 shows a significant brightness in photonic crystals (PhC) comparing with that in unpatterned films.

The combination of inhibiting undesirable emission by redistributing light energy into useful modes offers a promising approach in various applications for perovskite, including solar cells, displays and photovoltaics. The study is published in *ACS Photonics*. [17]

Studying chiral exchange drag and chirality oscillations in synthetic antiferromagnets

A quasiparticle is a disturbance or excitation (e.g. spin waves, bubbles, etc.) that behaves as a particle and could therefore be regarded as one. Long-range interactions between quasiparticles can give rise to a 'drag,' which affects the fundamental properties of many systems in condensed matter physics.

This drag generally involves an exchange of linear momentum between quasiparticles, which strongly influences their transport properties. Researchers at IBM and the Max Planck Institute have carried out a

study investigating this drag and chirality oscillations in synthetic antiferromagnets. In their paper, which was recently published in *Nature Physics*, they defined a new type of drag that involves the exchange of angular momentum between two current-driven magnetic domain walls.

"In recent years, I have worked on the interplay of spin current with chiral magnetic domain wall whose chirality is set by Dzyaloshinskii-Moriya interaction at interface," See-Hun Yang, an IBM researcher who carried out the study, told *Phys.org*.

In 2013, Yang and his colleagues showed that chiral domain walls can be efficiently moved by a relativistic spin-orbit interaction induced spin current, referred to as spin-orbit torque. Around the same time, this observation was also reported by a group of researchers at MIT.

A few years later, Yang and his colleagues observed that coupled chiral domain walls can move at much higher velocity (~ 1 km/s) by current, due to a powerful exchange coupling torque when they are antiferromagnetically coupled. Yang developed a model that could help to better understand these observations and also discovered a new powerful torque called exchange coupling torque.

"During the data fitting with my model, I spotted a strange anomaly phase in a certain parameter space in domain wall velocity versus applied longitudinal field curves that shows a high asymmetry," Yang explained. "I observed that a coupled domain wall gets dramatically slowed down at negative fields when the exchange coupling is relatively weak. For instance, my model showed that coupled domain velocity collapses from 500 m/s down to zero by application of merely -50 mT field."

Yang found that the dramatic reduction in velocity observed in his research was due to oscillation of coupled domain walls displacement. Most interestingly, he learned that domain wall magnetizations oscillate/precess in a way that is synchronously correlated with domain walls displacement.

"To observe this interesting novel phase, we started a new experiment by preparing devices formed from weakly coupled synthetic antiferromagnetic (SAF) films, which could be achieved by growing thinner Cobalt layers sandwiching Ruthenium spacer in SAF," Yang said. "Note that Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction induces exchange coupling between Cobalt layers across Ruthenium spacer layer."

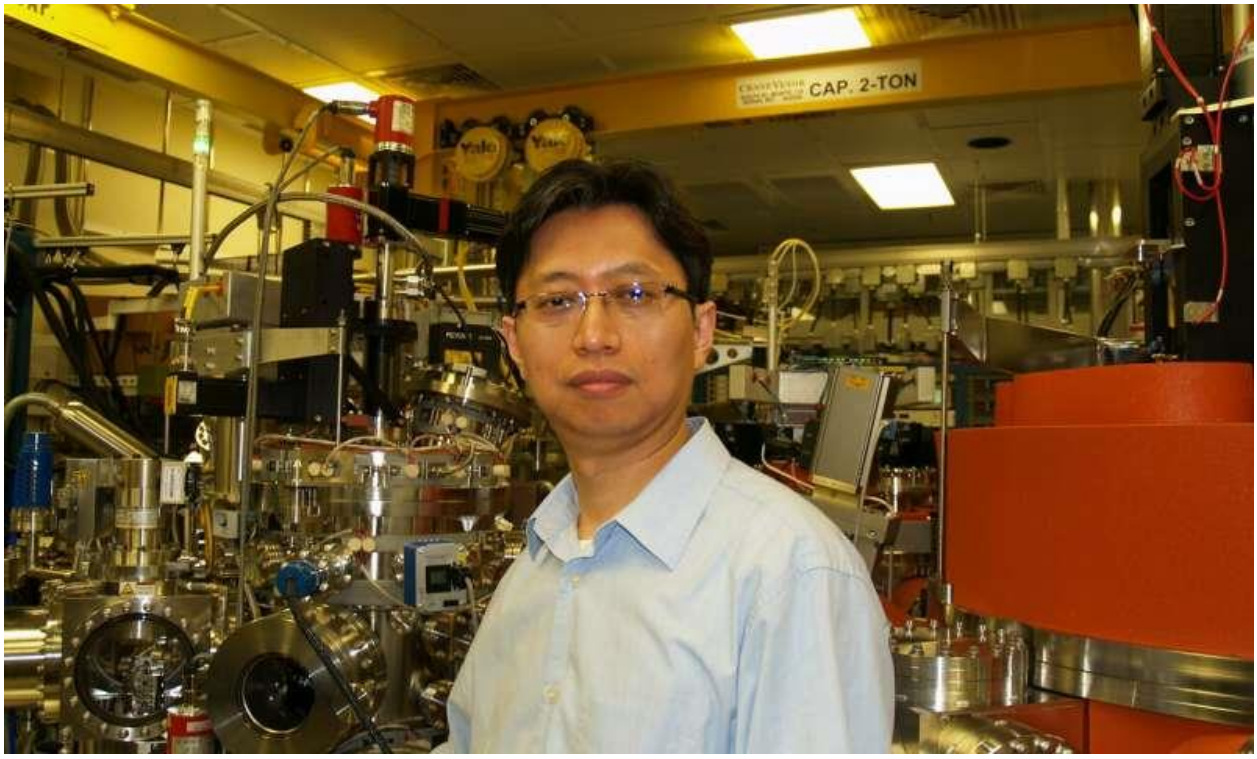
The strength and sign of RKKY interactions are sensitively dependent on the thickness of a Ruthenium layer. Since RKKY interactions are only sensitive to interfaces, given a particular Ruthenium layer thickness, the exchange coupling strength can be tuned further by thinning down the Cobalt layer below one monolayer.

"In our experiment, we luckily and immediately reproduced the highly asymmetric domain wall velocity-longitudinal field curve and dramatic collapse of domain wall velocity predicted by my model, which I was very excited about at the time," Yang said. "However, it took more than a year for me to fully understand the physical mechanism of this strange phase."

In an attempt to better understand his prior observations, Yang spent a long time looking into his model and rewriting coupled equations of motion in several different ways. He finally discovered that the strange dynamic phase he had observed was related to a kind of drag called chiral exchange drag (CED).

"When a current flows into two coupled sub-layers, different spin-orbit torques are exerted on chiral domain walls since the environment for each domain wall is not identical," Yang explained. "Consequently, one chiral domain wall moves faster than the other. However, since their positions are tightly bound to

each other, a faster domain wall "drags" a slower one. This means that the coupled domain walls move at the intermediate velocity, that is, average velocity weighted by their magnetizations."



See-Hun Yang, IBM.

This process does not immediately give rise to the strange phase observed by Yang, since at this stage the coupled domain walls still travel at a steady and reasonable velocity. However, as the drag increases and exceeds a threshold value, the structure of the chiral domain walls becomes unstable. In his research, Yang also found that the applied longitudinal field acts as a knob, which can be used to tune the drag strength.

"This unstable domain wall structure corresponds to the strange dynamic phase, and I dubbed it 'chiral exchange drag anomaly,'" Yang said. "I learned that in this phase the magnetization of slower chiral domain wall precesses, that is, the chirality oscillates. Essentially, in this chiral exchange drag anomaly phase, the kinetic energy of a large drag is converted to another internal DOF of angular momentum, that is, azimuthal rotation of domain wall magnetization, thus leading to a dramatic drop of average displacement of domain walls."

While he was developing his model, Yang also introduced two new concepts: quasi-domain walls and composite domains. Quasi-domain walls are fictitious domain walls constrained to sublayers in SAF wire, as if their positions are decoupled from each other and they move independently. Their magnetizations are dressed with exchange coupling interaction, therefore, quasi-domain walls are similar to quasi-particles. Composite domain walls, on the other hand, correspond to the actual coupled domain walls that are composed of position-locked quasi-domain walls.

"When I first described these concepts, I did not realize how important my findings were and what impact they would have in broad physics," Yang said. "Some time later, two further insights about the important

physical meaning of "drag" occurred me when I was traveling. The first one happened when I was on a train reading a review article about Coulomb drag."

Around the time he made this first realization, Yang had just discovered that while CED and Coulomb drag share many similarities, they also had substantial differences. For instance, in contrast with Coulomb drag, in CED chirality plays a key role, the positions of coupled chiral domain walls are bound to one another other, and the chiral domain walls have another internal DOF.

"I got a second insight when I was reading a chapter about Dirac equations from a quantum field theory textbook in a hotel room during a vacation," Yang said. "At the time, I was intrigued by surprising analogues between my CED and Dirac fermions. For example, chirality of coupled domain walls is constant in the steady state of CED. This is similar to massless Dirac ferimons that can be described by Weyl equations. In this case, chirality is a good quantum number and constant. On the other hand, as the Dirac fermions become massive, chirality is no longer an eigenstate such that the chirality oscillates with oscillating frequency that is linearly proportional to the mass. Similarly, in CED anomaly phase the chirality of slower domain wall oscillates with oscillating frequency that is almost linearly proportional to the net magnetization."

The new research carried out by Yang and his colleagues is based on his previous work and observations. In this study, they used magneto-optic Kerr microscopy to measure the current-driven chiral magnetic domain walls, which allowed them to spot their position. Before they applied current pulses, they took a Kerr image of wires patterned by weakly coupled SAF film.

"After applying a sequence of a few nanosecond long pulses to the wire, another Kerr image was taken," Yang explained. "The domain wall velocity could then be calculated from the domain wall displacement distance divided by current pulse length."

The researchers used a Kerr microscope equipped with electromagnets. This allowed them to apply in-plane and out-of-plane magnetic fields during the procedure described above.

Yang and his colleagues successfully defined a new form of drag, CED, which is derived from coupled chiral magnetic domain walls that are associated with an angular momentum transfer torque. In addition, they observed that the strength of this drag can be tuned by leveraging the chiral nature of domain walls.

Finally, the researchers observed a new domain wall dynamic phase, the CED anomaly phase outlined above, which takes place when the drag exceeds a threshold value. Interestingly, both CED and CED anomaly present striking similarities with other drag phenomena in condensed matter physics, such as Coulomb drag, as well as with Dirac fermions in high energy physics.

"We are witnessing the emergence of an exciting field, Chiral Spintronics, the marriage of spintronics to chirality, which has attracted enormous attention in magnetic and condensed matter physics communities," Yang said. "I think that CED and CED anomaly are an outstanding example of and a significant contribution to Chiral Spintronics. I am now planning to tackle other chiral systems such as chiral ferrimagnets and antiferromagnets and their interplay with moving spins." [16]

Antiferromagnets prove their potential for spin-based information technology

Within the emerging field of spin-based electronics, or spintronics, information is typically defined by the orientation of the magnetization of ferromagnets. Researchers have recently been also interested in the utilization of antiferromagnets, which are materials without macroscopic magnetization but with a staggered orientation of their microscopic magnetic moments. Here the information is encoded in the direction of the modulation of the magnetic moments, the so-called Néel vector. In principle, antiferromagnets enable much faster information-writing and are very stable with respect to disturbing external fields. These advantages, however, also imply a challenging manipulation and read-out processes of the Néel vector orientation. Up to now, this had been possible using the semimetal copper manganese arsenide CuMnAs only, a compound featuring several disadvantages concerning applications.

As published in the online science journal *Nature Communications*, scientists at the Institute of Phyics at Johannes Gutenberg University Mainz (JGU) were now able to demonstrate current-induced switching of the Néel vector also for metallic thin films of a compound consisting of manganese and gold, Mn2Au, which orders antiferromagnetically at high temperatures. In particular, they measured a ten times larger magnetoresistance as observed for CuMnAs. The surprising magnitude of this effect is explained by extrinsic scattering on excess gold atoms, as deduced from calculations done by Libor Šmejkal, who in the framework of a collaboration with the Czech Academy of Sciences is currently conducting his Ph.D. project in the group of Professor Jairo Sinova at Mainz University.

"These calculations are very important for the understanding of our experimental work mainly performed by Stanislav Bodnar, who is a Ph.D. student in our group. We identified Mn2Au as a prime candidate for enabling future antiferromagnetic spintronics," explained PD Dr. Martin Jourdan, project leader of the study. "Aside from the large magnetoresistance of this compound, other important advantages are its non-toxic composition and the fact that it can be used even at higher temperatures." [15]

Spin current detection in quantum materials unlocks potential for alternative electronics

A new method that precisely measures the mysterious behavior and magnetic properties of electrons flowing across the surface of quantum materials could open a path to next-generation electronics.

Found at the heart of electronic devices, silicon-based semiconductors rely on the controlled electrical current responsible for powering electronics. These semiconductors can only access the electrons' charge for energy, but electrons do more than carry a charge. They also have intrinsic angular momentum known as spin, which is a feature of quantum materials that, while elusive, can be manipulated to enhance electronic devices.

A team of scientists, led by An-Ping Li at the Department of Energy's Oak Ridge National Laboratory, has developed an innovative microscopy technique to detect the spin of electrons in

topological insulators, a new kind of quantum material that could be used in applications such as spintronics and quantum computing.

"The spin current, namely the total angular momentum of moving electrons, is a behavior in topological insulators that could not be accounted for until a spin-sensitive method was developed," Li said.

Electronic devices continue to evolve rapidly and require more power packed into smaller components. This prompts the need for less costly, energy-efficient alternatives to charge-based electronics. A topological insulator carries electrical current along its surface, while deeper within the bulk material, it acts as an insulator. Electrons flowing across the material's surface exhibit uniform spin directions, unlike in a semiconductor where electrons spin in varying directions.

"Charge-based devices are less energy efficient than spin-based ones," said Li. "For spins to be useful, we need to control both their flow and orientation."

To detect and better understand this quirky particle behavior, the team needed a method sensitive to the spin of moving electrons. Their new microscopy approach was tested on a single crystal of Bi2Te2Se, a material containing bismuth, tellurium and selenium. It measured how much voltage was produced along the material's surface as the flow of electrons moved between specific points while sensing the voltage for each electron's spin.

The new method builds on a four-probe scanning tunneling microscope—an instrument that can pinpoint a material's atomic activity with four movable probing tips—by adding a component to observe the spin behavior of electrons on the material's surface. This approach not only includes spin sensitivity measurements. It also confines the current to a small area on the surface, which helps to keep electrons from escaping beneath the surface, providing high-resolution results.

"We successfully detected a voltage generated by the electron's spin current," said Li, who coauthored a paper published by Physical Review Letters that explains the method. "This work provides clear evidence of the spin current in topological insulators and opens a new avenue to study other quantum materials that could ultimately be applied in next-generation electronic devices." [14]

Device design allows ten-fold increase in spin currents

An electron carries electrical charge and spin that gives rise to a magnetic moment and can therefore interact with external magnetic fields. Conventional electronics are based on the charge of the electron. The emerging field of spintronics aims to exploit the spin of the electron. Using spins as elementary units in computing and highly efficient electronics is the ultimate goal of spintronic science because of spintronics minimal energy use. In this study, researchers manipulated and amplified the spin current through the design of the layered structures, a vital step towards this goal.

For cell phones, computers, and other electronic devices, a major shortcoming is the generation of heat when electrons move around the electronic circuits. The energy loss significantly reduces the device efficiency. Ultimately, the heat limits the packing of components in high-density micro-

chips. Spintronics' promise is to eliminate this energy loss. It does so by just moving the electron spin without moving the electrons. Using design strategies such as those identified by this research could result in highly energy-efficient spintronics to replace today's electronics.

An important obstacle to realizing spintronics is the amplification of small spin signals. In conventional electronics, amplification of an electron current is achieved using transistors. Recently, researchers at Johns Hopkins University demonstrated that small spin currents can be amplified by inserting thin films of antiferromagnetic (materials in which the magnetic moments are canceled) insulator materials into the layered structures, effectively producing a spin-transistor. Scientists used thin films of antiferromagnetic insulators, such as nickel and cobalt oxide, sandwiched between ferrimagnetic insulator yttrium iron garnet (YIG) and normal metal films. With such devices, they showed that the pure spin current thermally injected from YIG into the metal can be amplified up to ten-fold by the antiferromagnetic insulator film. The researchers found that spin fluctuation of the antiferromagnetic insulating layer enhances the spin current. They also found that the amplification is linearly proportional to spin mixing conductance of the normal metal and the YIG. The experiments demonstrated this effect for various metals. Further, the study showed that the spin current amplification is proportional to the spin mixing conductance of YIG/metal systems for different metals. Calculations of the spin current enhancement and spin mixing conductance provided qualitative agreement with the experimental observations. [13]

Researchers road-test powerful method for studying singlet fission

In a new study, researchers measure the spin properties of electronic states produced in singlet fission – a process which could have a central role in the future development of solar cells.

Physicists have successfully employed a powerful technique for studying electrons generated through singlet fission, a process which it is believed will be key to more efficient solar energy production in years to come.

Their approach, reported in the journal Nature Physics, employed lasers, microwave radiation and magnetic fields to analyse the spin of excitons, which are energetically excited particles formed in molecular systems.

These are generated as a result of singlet fission, a process that researchers around the world are trying to understand fully in order to use it to better harness energy from the sun. Using materials exhibiting singlet fission in solar cells could make energy production much more efficient in the future, but the process needs to be fully understood in order to optimize the relevant materials and design appropriate technologies to exploit it.

In most existing solar cells, light particles (or photons) are absorbed by a semiconducting material, such as silicon. Each photon stimulates an electron in the material's atomic structure, giving a single electron enough energy to move. This can then potentially be extracted as electrical current.

In some materials, however, the absorption of a single photon initially creates one higher-energy, excited particle, called a spin singlet exciton. This singlet can also share its energy with another molecule, forming two lower-energy excitons, rather than just one. These lower-energy particles

are called spin "triplet" excitons. Each triplet can move through the molecular structure of the material and be used to produce charge.

The splitting process - from one absorbed photon to two energetic triplet excitons - is singlet fission. For scientists studying how to generate more solar power, it represents a potential bargain - a twofor-one offer on the amount of electrical current generated, relative to the amount of light put in. If materials capable of singlet fission can be integrated into solar cells, it will become possible to generate energy more efficiently from sunlight.

But achieving this is far from straightforward. One challenge is that the pairs of triplet excitons only last for a tiny fraction of a second, and must be separated and used before they decay. Their lifespan is connected to their relative "spin", which is a unique property of elementary particles and is an intrinsic angular momentum.

Studying and measuring spin through time, from the initial formation of the pairs to their decay, is essential if they are to be harnessed.

In the new study, researchers from the University of Cambridge and the Freie Universität Berlin (FUB) utilised a method that allows the spin properties of materials to be measured through time. The approach, called electron spin resonance (ESR) spectroscopy, has been used and improved since its discovery over 50 years ago to better understand how spin impacts on many different natural phenomena.

It involves placing the material being studied within a large electromagnet, and then using laser light to excite molecules within the sample, and microwave radiation to measure how the spin changes over time. This is especially useful when studying triplet states formed by singlet fission as these are difficult to study using most other techniques.

Because the excitons' spin interacts with microwave radiation and magnetic fields, these interactions can be used as an additional way to understand what happens to the triplet pairs after they are formed. In short, the approach allowed the researchers to effectively watch and manipulate the spin state of triplet pairs through time, following formation by singlet fission.

The study was led by Professor Jan Behrends at the Freie Universität Berlin (FUB), Dr Akshay Rao, a College Research Associate at St John's College, University of Cambridge, and Professor Neil Greenham in the Department of Physics, University of Cambridge.

Leah Weiss, a Gates-Cambridge Scholar and PhD student in Physics based at Trinity College, Cambridge, was the paper's first author. "This research has opened up many new questions," she said. "What makes these excited states either separate and become independent, or stay together as a pair, are questions that we need to answer before we can make use of them."

The researchers were able to look at the spin states of the triplet excitons in considerable detail. They observed pairs had formed which variously had both weakly and strongly-linked spin states, reflecting the co-existence of pairs that were spatially close and further apart. Intriguingly, the group found that some pairs which they would have expected to decay very quickly, due to their close proximity, actually survived for several microseconds.

"Finding those pairs in particular was completely unexpected," Weiss added. We think that they could be protected by their overall spin state, making it harder for them to decay. Continued research will focus on making devices and examining how these states can be harnessed for use in solar cells."

Professor Behrends added: "This interdisciplinary collaboration nicely demonstrates that bringing together expertise from different fields can provide novel and striking insights. Future studies will need to address how to efficiently split the strongly-coupled states that we observed here, to improve the yield from singlet fission cells."

Beyond trying to improve photovoltaic technologies, the research also has implications for wider efforts to create fast and efficient electronics using spin, so-called "spintronic" devices, which similarly rely on being able to measure and control the spin properties of electrons. [12]

Using light to move electrons and protons

In some chemical reactions both electrons and protons move together. When they transfer, they can move concertedly or in separate steps. Light-induced reactions of this sort are particularly relevant to biological systems, such as Photosystem II where plants use photons from the sun to convert water into oxygen.

To better understand how light can lead to the transfer of protons in a chemical reaction, a group of researchers from the University of North Carolina, Shanxi University in China, and Memorial University in Newfoundland have conducted adsorption studies on a new family of experiments to observe the transition that occurs when protons transfer between hydrogen-bonded complexes in solution . They provide evidence for new optical transitions characteristic of the direct transfer of a proton. This report recently appeared in the Proceedings of the National Academy of Sciences.

N-methyl-4,4'-bipyridinium cation (MQ+) serves as proton acceptor, where a proton will add to the non-methylated pyridinium amine. If proton transfer occurs, then MQ+ will form a radical cation (MQH+•) whose absorbance spectra in the UV/visible range can be compared to N, N'-dimethyl-4, 4'-bypyridinium (MV2+).

By using ultrafast laser flash photolysis measurements, they found direct evidence for a low energy absorption band between p-methoxyphenyl and the mehylviologen acceptor, MQ+. It appears at 360 nm and as early as 250 fs after the laser pulse. Based on these properties, it is clearly the product of proton transfer from the phenol to give MeOPhO•—H-MQ+.

The appearance of this reaction involving the transfer of both an electron and proton after absorbing a single photon is supported by the vibrational coherence of the radical cation and by it characteristic spectral properties. By inference, related transitions, which are often at low intensities, could play an important role in the degradation of certain biological molecules, such as DNA.

The appearance of these absorption bands could have theoretical significance. They demonstrate a way to use simple spectroscopic measurements to explore the intimate details of how these

reactions occur in nature. This provides new physical insight into processes that could be of broad biological and chemical relevance. [11]

A single ion impacts a million water molecules

EPFL researchers have found that water molecules are 10,000 times more sensitive to ions than previously thought.

Water is simple and complex at the same time. A single water molecule (H2O) is made up of only 3 atoms. Yet the collective behavior of water molecules is unique and continues to amaze us. Water molecules are linked together by hydrogen bonds that break and form several thousands of billions of times per second. These bonds provide water with unique and unusual properties. Living organisms contain around 60% water and salt. Deciphering the interactions among water, salt and ions is thus fundamentally important for understanding life.

Not 100 but 1,000,000 molecules react

Researchers at EPFL's Laboratory for fundamental BioPhotonics, led by Sylvie Roke, have probed the influence of ions on the structure of water with unprecedentedly sensitive measurements. According to their multi-scale analyses, a single ion has an influence on millions of water molecules, i.e. 10,000 times more than previously thought. In an article appearing in Science Advances, they explain how a single ion can "twist" the bonds of several million water molecules over a distance exceeding 20 nanometers causing the liquid to become "stiffer". "Until now it was not possible to see beyond a hundred molecules. Our measurements show that water is much more sensitive to ions than we thought," said Roke, who was also surprised by this result.

The molecules line up around the ions

Water molecules are made up of one negatively charged oxygen atom and two positively charged hydrogen atoms. The Mickey Mouse-shaped molecule therefore does not have the same charge at its center as at its extremities. When an ion, which is an electrically charged atom, comes into contact with water, the network of hydrogen bonds is perturbed. The perturbation spreads over millions of surrounding molecules, causing water molecules to align preferentially in a specific direction. This can be thought of as water molecules "stiffening their network" between the various ions.

From atomistic to macroscopic length scales

Water's behavior was tested with three different approaches: ultrafast optical measurements, which revealed the arrangement of molecules on the nanometric scale; a computer simulation on the atomic scale; and measurement of the water's surface structure and tension, which was done at the macroscopic level. "For the last method, we simply dipped a thin metal plate into the water and pulled gently using a tensiometer to determine the water's resistance," said Roke. "We observed that the presence of a few ions makes it easier to pull the plate out, that is, ions reduce the surface resistance of water. This strange effect had already been observed in 1941, but it remained unexplained until now. Through our multiscale analysis we were able to link it to ion-induced stiffening of the bulk hydrogen bond network: a stiffer bulk results in a comparatively more flexible surface."

Testing different salts and different "waters"

The researchers carried out the same experiment with 21 different salts: they all affected water in the same way. Then they studied the effect of ions on heavy water, whose hydrogen atoms are heavy isotopes (with an additional neutron in the nucleus). This liquid is almost indistinguishable from normal water. But here the properties are very different. To perturb the heavy water in the same way, it required a concentration of ions six times higher. Further evidence of the uniqueness of water.

No link with water memory

Roke and her team are aware that it might be tempting to link these stunning results to all sorts of controversial beliefs about water. They are however careful to distance themselves from any farfetched interpretation. "Our research has nothing to do with water memory or homeopathy," she said. "We collect scientific data, which are all verifiable. "To prove the role of water in homeopathy, another million-billion-billion water molecules would have to be affected to even come close, and even then we are not certain."

The new discovery about the behavior of water will be useful in fundamental research, and in other areas too. The interaction between water and ions is omnipresent in biological processes related to enzymes, ion channels and protein folding. Every new piece of knowledge gives greater insight into how life works. [10]

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) $M_p = n^2 M_e$

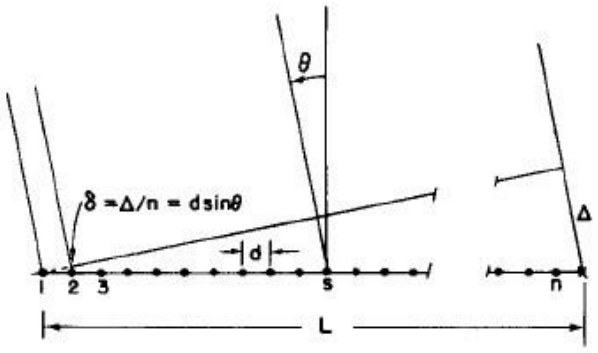


Fig. 30–3. A linear array of n equal oscillators, driven with phases $\alpha_s = s\alpha$.

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:

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

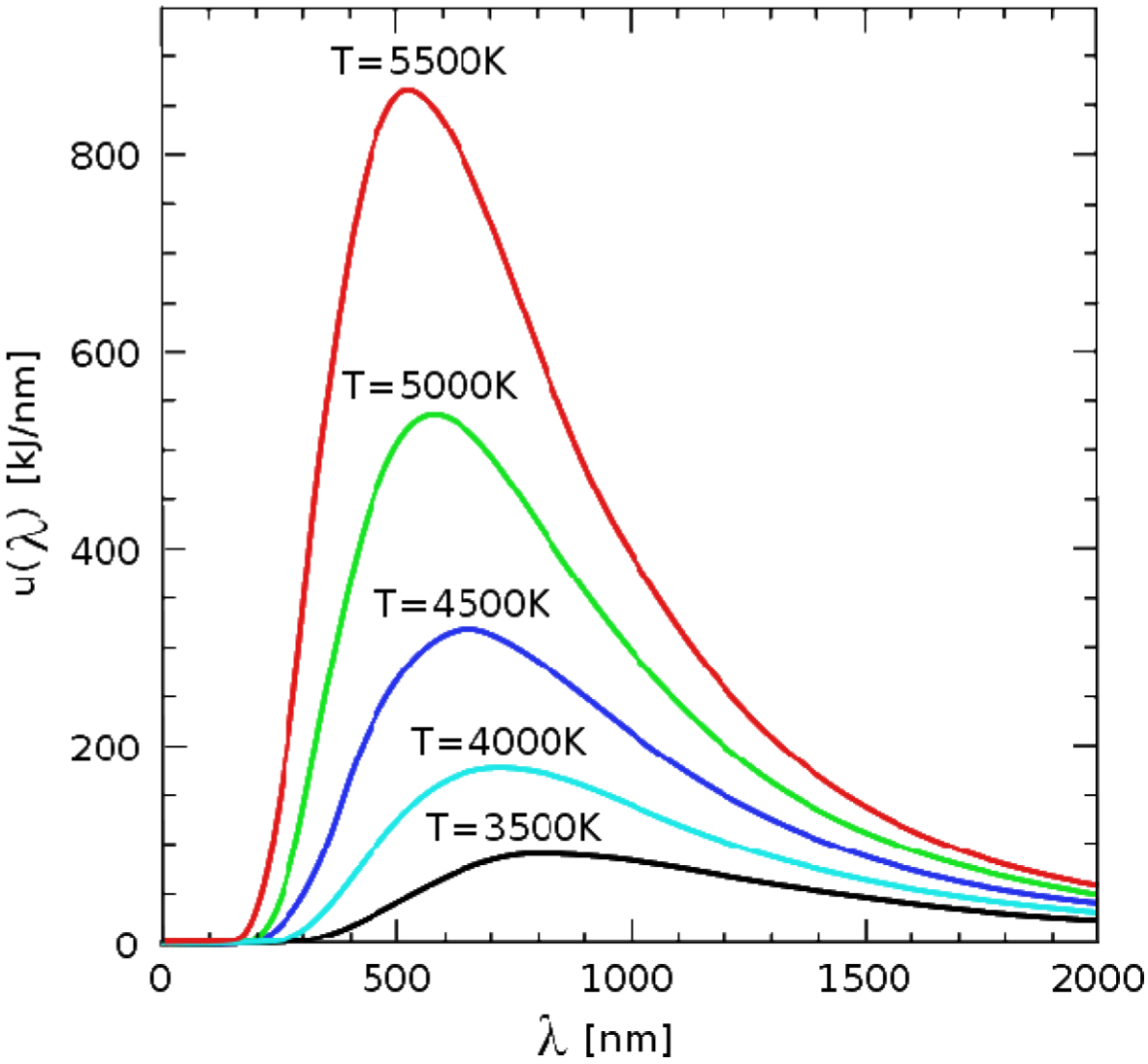


Figure 2. The distribution law for different T temperatures

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

"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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