Optical Laser Experiments at Atomic-Scale

The European X-ray Free-Electron Laser (XFEL) facility, near Hamburg, Germany, was built with one objective—to provide pulses of light short enough, bright enough, and of small enough wavelength to observe processes that would otherwise be too fast and/or too infrequent to measure in real-time. [18]

Smart phones have shiny flat AMOLED displays. Behind each single pixel of these displays hide at least two silicon transistors which were mass-manufactured using laser annealing technologies. [17]

Bumpy surfaces with graphene between would help dissipate heat in next-generation microelectronic devices, according to Rice University scientists. [16]

Scientists at The University of Manchester and Karlsruhe Institute of Technology have demonstrated a method to chemically modify small regions of graphene with high precision, leading to extreme miniaturisation of chemical and biological sensors. [15]

A new method for producing conductive cotton fabrics using graphene-based inks opens up new possibilities for flexible and wearable electronics, without the use of expensive and toxic processing steps. [14]

A device made of bilayer graphene, an atomically thin hexagonal arrangement of carbon atoms, provides experimental proof of the ability to control the momentum of electrons and offers a path to electronics that could require less energy and give off less heat than standard silicon-based transistors. It is one step forward in a new field of physics called valleytronics. [13]

In our computer chips, information is transported in form of electrical charge. Electrons or other charge carriers have to be moved from one place to another. For years scientists have been working on elements that take advantage of the electrons angular momentum (their spin) rather than their electrical charge. This new approach, called "spintronics" has major advantages compared to common electronics. It can operate with much less energy. [12]

Scientists have achieved the ultimate speed limit of the control of spins in a solid state magnetic material. The rise of the digital information era posed a daunting challenge to develop ever faster and smaller devices for data storage and processing. An approach which relies on the magnetic moment of electrons (i.e. the spin) rather than the charge, has recently turned into major research fields, called spintronics and magnonics. [11]

A team of researchers with members from Germany, the U.S. and Russia has found a way to measure the time it takes for an electron in an atom to respond to a pulse of light. [10]

As an elementary particle, the electron cannot be broken down into smaller particles, at least as far as is currently known. However, in a phenomenon called electron fractionalization, in certain materials an electron can be broken down into smaller "charge pulses," each of which carries a fraction of the electron's charge. Although electron fractionalization has many interesting implications, its origins are not well understood. [9]

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

Versatile optical laser will enable innovative experiments at atomic-scale measurements

The European X-ray Free-Electron Laser (XFEL) facility, near Hamburg, Germany, was built with one objective—to provide pulses of light short enough, bright enough, and of small enough wavelength to observe processes that would otherwise be too fast and/or too infrequent to measure in real-time.

Without such ultrashort pulses—and this means millionths of billionths of a second long (femtoseconds)—measurements are limited to a before-and-after look at molecular interactions. Six different end-stations will be available for scientists from across the globe to conduct experiments using the XFEL beam once it is fully functioning in 2017.

In order to make these measurements, the research team developed a high-power, pulsed, optical laser that is synchronized with the XFEL pulses and tunable in both wavelength and pulse duration to accommodate the needs of each of the six different experiments being conducted. The features of this versatile optical laser system will be published in a paper in the journal Optics Express, from The Optical Society (OSA).

"The real uniqueness of our laser lies in the fact that it matches the burst emission pattern of the European XFEL," said Max J. Lederer, lead scientist, XFEL. "It therefore enables experiments at the highest possible pulse rate of the XFEL with optical pulse parameters (energy, pulse duration) only obtainable at low repetition rates from Ti:Sapphire systems."

These days, finding an optical laser capable of producing ultrashort pulses for research, such as a titanium-sapphire (Ti:Sapph) laser, isn't difficult. But finding such a laser that can match the power and timing specifications of the six XFEL experiments is difficult. "In other words, it's the high repetition rate and average power during the bursts that make the difference," Lederer said.

But why would a facility built to house one of the largest and most advanced lasers, need another laser? In fact, this additional laser system is an integral part of performing the projected atomic-scale measurements. The optical laser pulses serve to prepare samples, using the interaction with it as the first step, in some sense as a control, before using the x-ray pulse to probe and investigate the unknown dynamics. It is mainly the "pump" part of the pump-probe experiments the laser is designed to perform.

"The laser system is [built] to satisfy the need for an experimental optical pump-probe laser, synchronized and adapted to the emission pattern of the European XFEL. The laser will typically activate samples, followed by probing with the X-ray pulses," Lederer said.

The need for tunability of the pump laser comes from each of the six scientific stations housing different experiments that investigate various sample types and phases of matter. The optical laser provides this configurability via a number of optical techniques that harness light-matter interactions to result in the precise energy and timing of the pulses needed.

One example of such a process is called parametric conversion which refers to the conversion of one particle of light into two of half the energy, or vice versa. "For enhanced experimental flexibility, the spectral range from UV to THz will be made available through parametric conversion and THz-generation schemes," Lederer said.

Installation of the first laser has already begun and Lederer and his team look ahead to the exciting capabilities of the facility. Lederer said, "We are of course keen to meet the deadline to deliver the 'first photon' together with the XFEL. Personally, I'm keen on seeing the laser utilized in as many scientific discoveries as possible in the future." [18]

How laser annealing technology can lead to production of ultrathin nanomaterials

Smart phones have shiny flat AMOLED displays. Behind each single pixel of these displays hide at least two silicon transistors which were mass-manufactured using laser annealing technologies.

While the traditional methods to make them uses temperatures above 1,000 °C, the laser technique reaches the same results at low temperatures even on plastic substrates (melting temperature below 300 °C). Interestingly, a similar procedure can be used to generate crystals of graphene. Graphene is a strong and thin nano-material made of carbon, its electric and heat-conductive properties have attracted the attention of scientists worldwide.

Prof. KEON Jae Lee's research group at the Center for Multidimensional Carbon Materials (http://cmcm.ibs.re.kr/html/cmcm_en/) within the Institute for Basic Science (IBS) and Prof. CHOI Sung-Yool's team at KAIST discovered graphene synthesis mechanism using laser-induced solid-state phase separation of single-crystal silicon carbide (SiC). This study, available on Nature Communications, clarifies how this laser technology can separate a complex compound (SiC) into its ultrathin elements of carbon and silicon.

Although several fundamental studies understood the effect of excimer lasers in transforming elemental materials like silicon, the laser interaction with more complex compounds like SiC has rarely been studied due to the complexity of compound phase transition and ultra-short processing time.

With high resolution microscope images and molecular dynamic simulations, scientists found that a single-pulse irradiation of xenon chloride excimer laser of 30 nanoseconds melts SiC, leading to the separation of a liquid SiC layer, a disordered carbon layer with graphitic domains (about 2.5 nm thick) on top surface and a polycrystalline silicon layer (about 5 nm) below carbon layer. Giving additional pulses causes the sublimation of the separated silicon, while the disordered carbon layer is transformed into a multilayer graphene.

"This research shows that the laser material interaction technology can be a powerful tool for next generation of two dimensional nanomaterials," said Prof. Keon. Prof. Choi added: "Using laser-induced phase separation of complex compounds, new types of two dimensional materials can be synthesized in the future." IBS Prof. Keon is affiliated with the School of Materials Science and Engineering, KAIST and Prof. Choi with the School of Electrical Engineering and Graphene Research Center, KAIST. [17]

Bumpy surfaces, graphene beat the heat in devices

Bumpy surfaces with graphene between would help dissipate heat in next-generation microelectronic devices, according to Rice University scientists.

Their theoretical studies show that enhancing the interface between gallium nitride semiconductors and diamond heat sinks would allow phonons – quasiparticles of sound that also carry heat – to disperse more efficiently. Heat sinks are used to carry heat away from electronic devices.

Rice computer models replaced the flat interface between the materials with a nanostructured pattern and added a layer of graphene, the atom-thick form of carbon, as a way to dramatically improve heat transfer, said Rice materials scientist Rouzbeh Shahsavari.

The new work by Shahsavari, Rice graduate student and lead author Lei Tao and postdoctoral researcher Sreeprasad Sreenivasan appeared this month in the American Chemical Society journal ACS Applied Materials and Interfaces.

No matter the size, electronic devices need to disperse the heat they produce, Shahsavari said. "With the current trend of constant increases in power and device miniaturization, efficient heat management has become a serious issue for reliability and performance," he said. "Oftentimes, the individual materials in hybrid nano- and microelectronic devices function well but the interface of different materials is the bottleneck for heat diffusion."

Gallium nitride has become a strong candidate for use in high-power, high-temperature applications like uninterruptible power supplies, motors, solar converters and hybrid vehicles, he said. Diamond is an excellent heat sink, but its atomic interface with gallium nitride is hard for phonons to traverse.

The researchers simulated 48 distinct grid patterns with square or round graphene pillars and tuned them to match phonon vibration frequencies between the materials. Sinking a dense pattern of small squares into the diamond showed a dramatic decrease in thermal boundary resistance of up to 80 percent. A layer of graphene between the materials further reduced resistance by 33 percent.

Fine-tuning the pillar length, size, shape, hierarchy, density and order will be important, Lei said.

"With current and emerging advancements in nanofabrication like nanolithography, it is now possible to go beyond the conventional planer interfaces and create strategically patterned interfaces coated with nanomaterials to significantly boost heat transport," Shahsavari said. "Our strategy is amenable to several other hybrid materials and provides novel insights to overcome the thermal boundary resistance bottleneck."

Shahsavari is an assistant professor of civil and environmental engineering and of materials science and nanoengineering.

The researchers used the Blue Gene supercomputer and the National Science Foundation-supported DAVinCI supercomputer, which are both administered by Rice's Center for Research Computing and were procured in partnership with Rice's Ken Kennedy Institute for Information Technology. [16]

Nano-calligraphy on graphene

Scientists at The University of Manchester and Karlsruhe Institute of Technology have demonstrated a method to chemically modify small regions of graphene with high precision, leading to extreme miniaturisation of chemical and biological sensors.

Writing in ACS Applied Materials & Interfaces, researchers led by Dr. Aravind Vijayaraghavan have shown that it is possible to combine graphene with chemical and biological molecules and form patterns, which are 100s of nanometres wide.

Graphene is the world's first two-dimensional material. It is strong, transparent, flexible and the world's most conductive material. Every atom in graphene is exposed to its environment, allowing it to sense changes in its surroundings.

Using technology that resembles writing with a quill or fountain pen, the scientists were able to deliver chemical droplets to the surface of graphene in very small volumes. In order to achieve such fine chemical patterns, the researchers used droplets of chemicals less than 100 attolitres (10-16 L) in volume.

These techniques are key to enabling graphene sensors which can be used in real-world applications; graphene sensors fabricated this way have the potential to be used in blood tests, minimising the amount of blood a patient is required to give.

Dr. Vijayaraghavan explains: "Two types of 'pens' were used, one which is dipped into the reactive 'ink' like a quill to cover the nib, and the other where the ink is filled into a reservoir and flows through a channel in the nib, just like in a fountain pen. An array of such micro-pens are moved over the graphene surface to deliver the chemical droplets which react with the graphene. The first method is known as Dip-Pen Nanolithography (DPN) and the latter is known as Microchannel Cantilever Spotting (µCS)."

Dr. Michael Hirtz, co-investigator from Karlsruhe adds: "By chemically modifying the graphene in such small regions, we can develop chemical and biological sensors which only require very small volumes of fluid to detect various constituents. This, combined with the high sensitivity of graphene sensors, leads us to imagine that in the future we could perform a full blood test on a patient with just one tiny drop of blood, instead of a full syringe." [15]

Environmentally-friendly graphene textiles could enable wearable electronics

A new method for producing conductive cotton fabrics using graphene-based inks opens up new possibilities for flexible and wearable electronics, without the use of expensive and toxic processing steps.

Wearable, textiles-based electronics present new possibilities for flexible circuits, healthcare and environment monitoring, energy conversion, and many others. Now, researchers at the Cambridge Graphene Centre (CGC) at the University of Cambridge, working in collaboration with scientists at Jiangnan University, China, have devised a method for depositing graphene-based inks onto cotton to produce a conductive textile. The work, published in the journal Carbon, demonstrates a wearable motion sensor based on the conductive cotton.

Cotton fabric is among the most widespread for use in clothing and textiles, as it is breathable and comfortable to wear, as well as being durable to washing. These properties also make it an excellent choice for textile electronics. A new process, developed by Dr Felice Torrisi at the CGC, and his collaborators, is a low-cost, sustainable and environmentally-friendly method for making conductive cotton textiles by impregnating them with a graphene-based conductive ink.

Based on Dr Torrisi's work on the formulation of printable graphene inks for flexible electronics, the team created inks of chemically modified graphene flakes that are more adhesive to cotton fibres than unmodified graphene. Heat treatment after depositing the ink on the fabric improves the conductivity of the modified graphene. The adhesion of the modified graphene to the cotton fibre is similar to the way cotton holds coloured dyes, and allows the fabric to remain conductive after several washes.

Although numerous researchers around the world have developed wearable sensors, most of the current wearable technologies rely on rigid electronic components mounted on flexible materials such as plastic films or textiles. These offer limited compatibility with the skin in many circumstances, are damaged when washed and are uncomfortable to wear because they are not breathable.

"Other conductive inks are made from precious metals such as silver, which makes them very expensive to produce and not sustainable, whereas graphene is both cheap, environmentally-friendly, and chemically compatible with cotton," explains Dr Torrisi.

Co-author Professor Chaoxia Wang of Jiangnan University adds: "This method will allow us to put electronic systems directly into clothes. It's an incredible enabling technology for smart textiles."

The work done by Dr Torrisi and Prof Wang, together with students Tian Carey and Jiesheng Ren, opens a number of commercial opportunities for graphene-based inks, ranging from personal health technology, high-performance sportswear, military garments, wearable technology/computing and fashion.

"Turning cotton fibres into functional electronic components can open to an entirely new set of applications from healthcare and wellbeing to the Internet of Things," says Dr Torrisi "Thanks to nanotechnology, in the future our clothes could incorporate these textile-based electronics and become interactive."

Graphene is carbon in the form of single-atom-thick membranes, and is highly conductive. The group's work is based on the dispersion of tiny graphene sheets, each less than one nanometre thick, in a water-based dispersion. The individual graphene sheets in suspension are chemically modified to adhere well to the cotton fibres during printing and deposition on the fabric, leading to a thin and uniform conducting network of many graphene sheets. This network of nanometre flakes is the secret to the high sensitivity to strain induced by motion. A simple graphene-coated smart cotton textile used as a wearable strain sensor has been shown to reliably detect up to 500 motion cycles, even after more than 10 washing cycles in normal washing machine.

The use of graphene and other related 2D materials (GRMs) inks to create electronic components and devices integrated into fabrics and innovative textiles is at the centre of new technical advances in the smart textiles industry. Dr Torrisi and colleagues at the CGC are also involved in the Graphene Flagship, an EC-funded, pan-European project dedicated to bringing graphene and GRM technologies to commercial applications.

Graphene and GRMs are changing the science and technology landscape with attractive physical properties for electronics, photonics, sensing, catalysis and energy storage. Graphene's atomic thickness and excellent electrical and mechanical properties give excellent advantages, allowing deposition of extremely thin, flexible and conductive films on surfaces and – with this new method – also on textiles. This combined with the environmental compatibility of graphene and its strong adhesion to cotton make the graphene-cotton strain sensor ideal for wearable applications.

The research was supported by grants from the European Research Council's Synergy Grant, the International Research Fellowship of the National Natural Science Foundation of China and the Ministry of Science and Technology of China. The technology is being commercialised by Cambridge Enterprise, the University's commercialisation arm. [14]

Device to control 'color' of electrons in graphene provides path to future electronics

A device made of bilayer graphene, an atomically thin hexagonal arrangement of carbon atoms, provides experimental proof of the ability to control the momentum of electrons and offers a path to electronics that could require less energy and give off less heat than standard silicon-based transistors. It is one step forward in a new field of physics called valleytronics.

"Current silicon-based transistor devices rely on the charge of electrons to turn the device on or off, but many labs are looking at new ways to manipulate electrons based on other variables, called degrees of freedom," said Jun Zhu, associate professor of physics, Penn State, who directed the research. "Charge is one degree of freedom. Electron spin is another, and the ability to build transistors based on spin, called spintronics, is still in the development stage. A third electronic degree of freedom is the valley state of electrons, which is based on their energy in relation to their momentum."

Think of electrons as cars and the valley states as blue and red colors, Zhu suggested, just as a way to differentiate them. Inside a sheet of bilayer graphene, electrons will normally occupy both red and blue valley states and travel in all directions. The device her Ph.D. student, Jing Li, has been working on can make the red cars go in one direction and the blue cars in the opposite direction.

"The system that Jing created puts a pair of gates above and below a bilayer graphene sheet. Then he adds an electric field perpendicular to the plane," Zhu said.

"By applying a positive voltage on one side and a negative voltage on the other, a bandgap opens in bilayer graphene, which it doesn't normally have," Li explained.
"In the middle, between the two sides, we leave a physical gap of about 70 nanometers."

Inside this gap live one-dimensional metallic states, or wires, that are color-coded freeways for electrons. The red cars travel in one direction and the blue cars travel in the opposite direction. In theory, colored electrons could travel unhindered along the wires for a long distance with very little resistance. Smaller resistance means power consumption is lower in electronic devices and less heat is generated. Both power consumption and thermal management are challenges in current miniaturized devices.

"Our experiments show that the metallic wires can be created," Li said. "Although we are still a long way from applications."

Zhu added, "It's quite remarkable that such states can be created in the interior of an insulating bilayer graphene sheet, using just a few gates. They are not yet resistance-free, and we are doing more experiments to understand where resistance might come from. We are also trying to build valves that control the electron flow based on the color of the electrons. That's a new concept of electronics called valleytronics."

Li worked closely with the technical staff of Penn State's nanofabrication facility to turn the theoretical framework into a working device.

"The alignment of the top and bottom gates was crucial and not a trivial challenge," said Chad Eichfeld, nanolithography engineer. "The state-of-the-art electron beam lithography capabilities at the Penn State Nanofabrication Laboratory allowed Jing to create this novel device with nanoscale features." [13]

Researchers propose new method for creating extremely strong spin currents

In our computer chips, information is transported in form of electrical charge. Electrons or other charge carriers have to be moved from one place to another. For years scientists have been working on elements that take advantage of the electrons angular momentum (their spin) rather than their electrical charge. This new approach, called "spintronics" has major advantages compared to common electronics. It can operate with much less energy.

However, it is difficult to create such a spin current, which is required in spintronics. In the journal Physical Review Letters, physicists from TU Wien (Vienna) have now proposed a new method to produce gigantic spin currents in a very small period of time. The secret is using ultra short laser pulses.

Magnets and Semiconductors

For every electron, two different spin-states are possible; they are called "spin up" and "spin down". The electron spin is responsible for ferromagnetism: when many electron spins in a metal are aligned, they can collectively create a magnetic field. Therefore, using ferromagnets to create spin flux seems like a straightforward idea. "There have been attempts to send an electric current through a combination of magnets and semiconductors", says Professor Karsten Held (TU Wien). "The idea is to create a flux of electrons with uniform spin, which can then be used for spintronic circuits. But the efficiency of this method is very limited."

Karsten Held and Marco Battiato found another way. In computer simulations, they analysed the behaviour of electrons in a thin layer of nickel when it is attached to silicon and hit with ultra short laser pulses. "Such a laser pulse has an overwhelming effect on the electrons in nickel", says Marco Battiato. They are swept away and accelerated towards the silicon.

An electric field builds up at the interface between nickel and silicon, which stops the current. Electrons still keep on migrating between the nickel layer and silicon, but the motion in both directions cancel each other, there is no net charge transfer.

Spin Up and Spin Down

But even when no electric charge is transported, it is still possible to transport spin. "In the nickel layer, there are both spin-up electrons as well as spin-down electrons", says Karsten Held. "But the metal atoms influence both kinds of electrons in different ways. The spin-up electrons can move rather freely. The spin-down electrons however have a much higher probability of being scattered at the nickel atoms."

When the electrons are scattered, they change their direction and lose energy. Therefore, the majority of the electrons which do make it all the way to the nickel-silicon interface are spin-up electrons. Electrons which move in the opposite direction have equal probabilities of being in the spin-up or spin-down state.

This spin-selective effect leads to a dominance of spin-up electrons in the silicon. This means that a spin current has been injected into the silicon without creating a charge current. "Our calculations show that this spin-polarization is extremely strong—much stronger than we could create with other methods", says Marco Battiato.

"And this spin flux can be created in femtoseconds." Time is of the essence: today's computer processors operate with gigahertz frequencies. Billions of operations per second are possible. Even higher frequencies in the terahertz range can only be reached with extremely fast elements.

So far, the method has only been tested in computer simulations. But Battiato and Held are already working with experimentalists who want to measure this laser-triggered spin flux. "Spintronics has the potential to become a key technology of the next few decades", says Held. "With our spin injection method there is now finally a way to create ultrafast, extremely strong spin currents." [12]

Femtosecond Laser pulses push Spintronics and Magnonics to the limit

Scientists have achieved the ultimate speed limit of the control of spins in a solid state magnetic material. The rise of the digital information era posed a daunting challenge to develop ever faster and smaller devices for data storage and processing. An approach which relies on the magnetic moment of electrons (i.e. the spin) rather than the charge, has recently turned into major research fields, called spintronics and magnonics.

The researchers were able to induce spin oscillations of the intrinsically highest frequency by using femtosecond laser pulses (1 fs = 10-15 sec). Furthermore, they demonstrated a complete and arbitrary manipulation of the phase and the amplitude of these magnetic oscillations – also called magnons. The length-scale of these magnons is on the order of 1 nanometre.

These results pave the way to the unprecedented frequency range of 20 THz for magnetic recording devices, which can be employed also at the nanometer scale.

The practical implementation of other schemes of magnetic control, based on the use of electric currents, is hampered by a significant heating which requires cooling systems. It is thus important to underline that the concept in the current publication does not involve any heating. This makes the study appealing from the point of view of future applications. However, the possibility to monitor the evolution of a magnet on such short time- and length- scales simultaneously is a major breakthrough also in terms of fundamental science. A new regime, defined by Dr. Bossini as femto-nanomagnonics, has been disclosed. [11]

Superfast light pulses able to measure response time of electrons to light

A team of researchers with members from Germany, the U.S. and Russia has found a way to measure the time it takes for an electron in an atom to respond to a pulse of light. In their paper published in the journal Nature, the team describes their use of a light field synthesizer to create pulses of light so fast that they were able to reveal the time it took for electrons in an atom to respond when struck. Kyung Taec Kim with the Gwangju Institute of Science offers a News & Views piece on the work done by the team in the same journal issue, outlining their work and noting one issue that still needs to be addressed with such work.

As scientists have begun preparing for the day when photons will replace electrons in high speed computers, work is being done to better understand the link between the two. One important aspect of this is learning what happens when photons strike electrons that remain in their atom (rather than being knocked out of them), specifically, how long does it take them to respond.

To find this answer, the researchers used what has come to be known as a light-field synthesizer—it is a device that is able to produce pulses of light that are just half of a single wavelength long—something many had thought was impossible not too long ago. The pulses are of such short duration that they only last for the time it takes to travel that half wavelength, which in this case, was approximately 380 attoseconds.

The light-field synthesizer works by combining several pulses of light brought together but slightly out of phase, allowing for canceling and ultimately, a single very short pulse. In their experiments, the researchers fired their super-short pulses at krypton atoms held inside of a vacuum. In so doing, they found that it took the electrons 115 attoseconds to respond—the first such measurement of the response time of an electron to a visible light pulse.

The team plans to continue their work by looking at how electrons behave in other materials, and as Kim notes, finding a way to characterize both the amplitude and phase of radiation from atoms driven by a light field. [10]

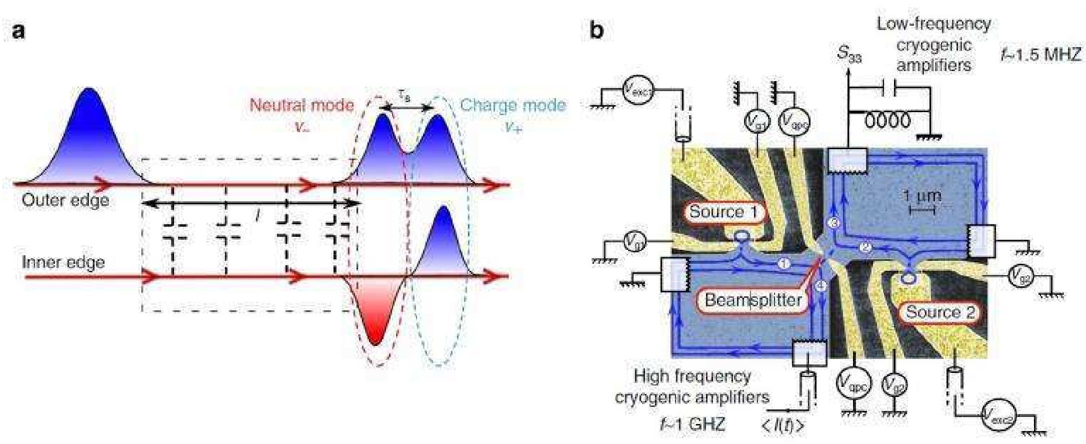
When an electron splits in two

Now in a new paper published in Nature Communications, a team of physicists led by Gwendal Fève at the Ecole Normale Supérieure in Paris and the Laboratory for Photonics and Nanostructures in Marcoussis have applied an experiment typically used to study photons to investigate the underlying mechanisms of electron fractionalization. The method allows the researchers to observe single-electron fractionalization on the picosecond scale.

"We have been able to visualize the splitting of an electronic wavepacket into two fractionalized packets carrying half of the original electron charge," Fève told Phys.org. "Electron fractionalization has been studied in previous works, mainly during roughly the last five years. Our work is the first to combine single-electron resolution—which allows us to address the fractionalization process at the elementary scale—with time resolution to directly visualize the fractionalization process."

The technique that the researchers used is called the Hong-Ou-Mandel experiment, which can be used to measure the degree of resemblance between two photons, or in this case electron charge pulses, in an interferometer. This experiment also requires a single-electron emitter, which some of the same researchers, along with many others, have recently been developing.

The researchers first analyzed the propagation of a single electron in the interferometer's outer one-dimensional wire, and then when that electron fractionalized, they could observe the interaction between its two charge pulses in the inner one-dimensional wire. As the researchers explain, when the original electron travels along the outer wire, Coulomb interactions (interactions between charged particles) between excitations in the outer and inner wires produce two types of excitation pairs: two pulses of the same sign (carrying a net charge) and two pulses of opposite signs (which together are neutral). The two different excitation pairs travel at different velocities, again due to Coulomb interactions, which causes the original electron to split into two distinct charge pulses.



(a) An electron on the outer channel fractionalizes into two pulses. (b) A modified scanning electron microscope picture of the sample. Credit: Freulon, et al. ©2015 Nature

The experiment reveals that, when a single electron fractionalizes into two pulses, the final state cannot be described as a single-particle state, but rather as a collective state composed of several excitations. For this reason, the fractionalization process destroys the original electron particle. Electron destruction can be measured by the decoherence of the electron's wave packet.

Gaining a better understanding of electron fractionalization could have a variety of implications for research in condensed matter physics, such as controlling single-electron currents in one-dimensional wires.

"There has been, during the past years, strong efforts to control and manipulate the propagation of electrons in electronic conductors," Fève said. "It bears many analogies with the manipulations of the quantum states of photons performed in optics. For such control, one-dimensional conductors are useful, as they offer the possibility to guide the electrons along a one-dimensional trajectory. However, Coulomb interactions between electrons are also very strong in one-dimensional wires, so strong that electrons are destroyed: they fractionalize. Understanding fractionalization is understanding the destruction mechanism of an elementary electron in a one-dimensional wire. Such understanding is very important if one wants to control electronic currents at the elementary scale of a single electron."

In the future, the researchers plan to perform further experiments with the Hong-Ou-Mandel interferometer in order to better understand why fractionalization leads to electron destruction, and possibly how to suppress fractionalization.

"The Hong-Ou-Mandel interferometer can be used to picture the temporal extension (or shape) of the electronic wavepackets, which is what we used to visualize the fractionalization process," Fève said. "It can also be used to capture the phase relationship (or phase coherence) between two components of the electronic wavepacket.

"This combined information fully defines the single-electron state, offering the possibility to visualize the wavefunction of single electrons propagating in a one-dimensional conductor. This would first provide a complete understanding of the fractionalization mechanism and in particular how it leads to the decoherence of single-electron states. It would also offer the possibility to test if single electrons can be protected from this decoherence induced by Coulomb interaction. Can we suppress (or reduce) the fractionalization process by reducing the strength of the Coulomb interaction? We would then be able to engineer and visualize pure single-electron states, preserved from Coulomb interaction.

"The next natural step is then to address few-particle states and electron entanglement in quantum conductors. Again, the question of the destruction of such states by Coulomb interaction effects will be a crucial one." [9]

The Electromagnetic Interaction

This paper explains the magnetic effect of the electric current from the observed effects of the accelerating electrons, causing naturally the experienced changes of the electric field potential along the electric wire. The accelerating electrons explain not only the Maxwell Equations and the Special Relativity, but the Heisenberg Uncertainty Relation, the wave particle duality and the electron's spin also, building the bridge between the Classical and Quantum Theories. [2]

Asymmetry in the interference occurrences of oscillators

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

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

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

(1) $I = I_0 \sin^2 n\, \phi/2 \,/\, \sin^2 \phi/2$

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

(2) $I = n^2 I_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

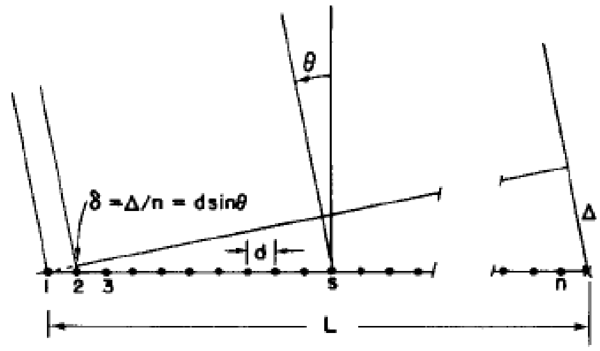


Fig. 30–3. A linear array of n equal oscillators, driven with phases $\alpha_s = s\alpha$.

Figure 1.) A linear array of n equal oscillators

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

So

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

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

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

For example

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

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

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

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

Spontaneously broken symmetry in the Planck distribution law

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

Max Planck found for the black body radiation

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

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

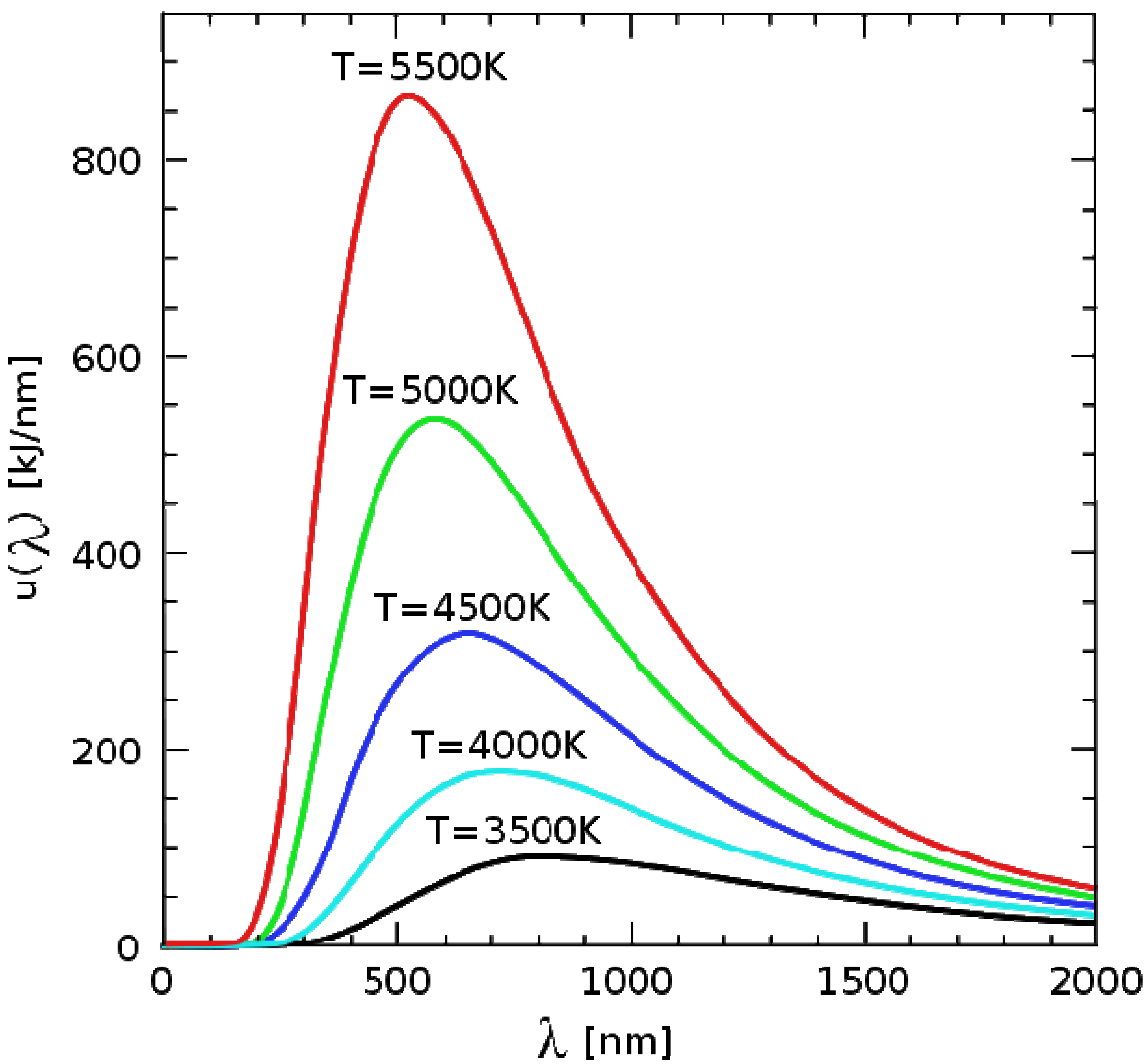


Figure 2. The distribution law for different T temperatures

We see there are two different λ_1 and λ_2 for each T and intensity, so we can find between them a d so that $\lambda_1 < d < \lambda_2$.

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

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

> where λ_{max} is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977685(51)\times10^{-3}$ m·K (2002 CODATA recommended value).

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

The structure of the proton

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

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

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

The Strong Interaction

Confinement and Asymptotic Freedom

For any theory to provide a successful description of strong interactions it should simultaneously exhibit the phenomena of confinement at large distances and asymptotic freedom at short distances. Lattice calculations support the hypothesis that for non-abelian gauge theories the two domains are analytically connected, and confinement and asymptotic freedom coexist.
Similarly, one way to show that QCD is the correct theory of strong interactions is that the coupling extracted at various scales (using experimental data or lattice simulations) is unique in the sense that its variation with scale is given by the renormalization group. [4]
Lattice QCD gives the same results as the diffraction theory of the electromagnetic oscillators, which is the explanation of the strong force and the quark confinement. [1]

The weak interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

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

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

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

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

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

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

The General Weak Interaction

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

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

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

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

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

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction. [5]

Fermions and Bosons

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

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

The fermions' spin

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

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

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

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

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The source of the Maxwell equations

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

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

Also an interesting question, how the changing magnetic field creates a negative electric field?
The answer also the accelerating electrons will give. When the magnetic field is increasing in time by

increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change.
In this way we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.
The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.
There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by week interaction and can be understood by the Feynman graphs.
Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greatest proton mass.

The Special Relativity

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

The Heisenberg Uncertainty Principle

Moving faster needs stronger acceleration reducing the dx and raising the dp. It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass rate since the dx is much less requiring bigger dp in the case of the proton, which is partly the result of a bigger mass m_p because of the higher electromagnetic induction of the bigger frequency (impulse).

The Gravitational force

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

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Bing Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

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

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

The mass as seen before a result of the diffraction, for example the proton – electron mass rate M_p = 1840 M_e. In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass. [1]

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.
There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

The Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [3]

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Casimir effect

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

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light. In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass. This means that the electron is not a point like particle, but has a real charge distribution.

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

The Fine structure constant

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

$$E = h\nu\,.$$

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

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

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

The expression of the fine-structure constant becomes the abbreviated

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

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

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

Path integral formulation of Quantum Mechanics

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

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

Conclusions

"The next natural step is then to address few-particle states and electron entanglement in quantum conductors. Again, the question of the destruction of such states by Coulomb interaction effects will be a crucial one." [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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