# Imaging Algorithm

*MIT researchers have developed a technique for recovering visual information from light that has scattered because of interactions with the environment—such as passing through human tissue. [15]*

*Measurement of the twisting force, or torque, generated by light on a silicon chip holds promise for applications such as miniaturized gyroscopes and sensors to measure magnetic field, which can have significant industrial and consumer impact. [14]*

*A new technique detects spatial coherence in light at smaller scales than had been possible. [13]*

*Powerful laser beams, given the right conditions, will act as their own lenses and "self-focus" into a tighter, even more intense beam. University of Maryland physicists have discovered that these self-focused laser pulses also generate violent swirls of optical energy that strongly resemble smoke rings. [12]*

*Electrons fingerprint the fastest laser pulses. [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.*

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## Algorithm could enable visible-light-based imaging for medical devices, autonomous vehicles

MIT researchers have developed a technique for recovering visual information from light that has scattered because of interactions with the environment—such as passing through human tissue.

The technique could lead to medical-imaging systems that use visible light, which carries much more information than X-rays or ultrasound waves, or to computer vision systems that work in fog or drizzle. The development of such vision systems has been a major obstacle to self-driving cars.

In experiments, the researchers fired a laser beam through a "mask"—a thick sheet of plastic with slits cut through it in a certain configuration, such as the letter A —and then through a 1.5-centimeter "tissue phantom," a slab of material designed to mimic the optical properties of human tissue for purposes of calibrating imaging systems. Light scattered by the tissue phantom was then collected by a high-speed camera, which could measure the light's time of arrival.

From that information, the researchers' algorithms were able to reconstruct an accurate image of the pattern cut into the mask.

"The reason our eyes are sensitive only in this narrow part of the spectrum is because this is where light and matter interact most," says Guy Satat, a graduate student at the MIT Media Lab and first author on the new paper. "This is why X-ray is able to go inside the body, because there is very little interaction. That's why it can't distinguish between different types of tissue, or see bleeding, or see oxygenated or deoxygenated blood."

The imaging technique's potential applications in automotive sensing may be even more compelling than those in medical imaging, however. Many experimental algorithms for guiding autonomous vehicles are highly reliable under good illumination, but they fall apart completely in fog or drizzle; computer vision systems misinterpret the scattered light as having reflected off of objects that don't exist. The new technique could address that problem.

Satat's coauthors on the new paper, published today in Scientific Reports, are three other members of the Media Lab's Camera Culture group: Ramesh Raskar, the group's leader, Satat's thesis advisor, and an associate professor of media arts and sciences; Barmak Heshmat, a research scientist; and Dan Raviv, a postdoc.

### *Expanding circles*

Like many of the Camera Culture group's projects, the new system relies on a pulsed laser that emits ultrashort bursts of light, and a high-speed camera that can distinguish the arrival times of different groups of photons, or light particles. When a light burst reaches a scattering medium, such as a tissue phantom, some photons pass through unmolested; some are only slightly deflected from a straight path; and some bounce around inside the medium for a comparatively long time.

The first photons to arrive at the sensor have thus undergone the least scattering; the last to arrive have undergone the most.

Where previous techniques have attempted to reconstruct images using only those first, unscattered photons, the MIT researchers' technique uses the entire optical signal. Hence its name: all-photons imaging.

The data captured by the camera can be thought of as a movie—a two-dimensional image that changes over time. To get a sense of how all-photons imaging works, suppose that light arrives at the camera from only one point in the visual field. The first photons to reach the camera pass through the scattering medium unimpeded: They show up as just a single illuminated pixel in the first frame of the movie.

The next photons to arrive have undergone slightly more scattering, so in the second frame of the video, they show up as a small circle centered on the single pixel from the first frame. With each successive frame, the circle expands in diameter, until the final frame just shows a general, hazy light.

The problem, of course, is that in practice the camera is registering light from many points in the visual field, whose expanding circles overlap. The job of the researchers' algorithm is to sort out which photons illuminating which pixels of the image originated where.

## *Cascading probabilities*

The first step is to determine how the overall intensity of the image changes in time. This provides an estimate of how much scattering the light has undergone: If the intensity spikes quickly and tails off quickly, the light hasn't been scattered much. If the intensity increases slowly and tails off slowly, it has.

On the basis of that estimate, the algorithm considers each pixel of each successive frame and calculates the probability that it corresponds to any given point in the visual field. Then it goes back to the first frame of video and, using the probabilistic model it has just constructed, predicts what the next frame of video will look like.

With each successive frame, it compares its prediction to the actual camera measurement and adjusts its model accordingly. Finally, using the final version of the model, it deduces the pattern of light most likely to have produced the sequence of measurements the camera made.

One limitation of the current version of the system is that the light emitter and the camera are on opposite sides of the scattering medium. That limits its applicability for medical imaging, although Satat believes that it should be possible to use fluorescent particles known as fluorophores, which can be injected into the bloodstream and are already used in medical imaging, as a light source. And fog scatters light much less than human tissue does, so reflected light from laser pulses fired into the environment could be good enough for automotive sensing.

"People have been using what is known as time gating, the idea that photons not only have intensity but also time-of-arrival information and that if you gate for a particular time of arrival you get photons with certain specific path lengths and therefore [come] from a certain specific depth in the object," says Ashok Veeraraghavan, an assistant professor of electrical and computer engineering at Rice University. "This paper is taking that concept one level further and saying that even the photons that arrive at slightly different times contribute some spatial information."

"Looking through scattering media is a problem that's of large consequence," he adds. But he cautions that the new paper does not entirely solve it. "There's maybe one barrier that's been crossed, but there are maybe three more barriers that need to be crossed before this becomes practical," he says. [15]

## Photons do the twist, and scientists can now measure it

Researchers in the University of Minnesota's College of Science and Engineering have measured the twisting force, or torque, generated by light on a silicon chip.

Their work holds promise for applications such as miniaturized gyroscopes and torsional sensors to measure magnetic field, which can have significant industrial and consumer impact.

The new study, entitled "Optomechanical measurement of photon spin angular momentum and optical torque in integrated photonic devices" was published in the American Association for the Advancement of Science's journal Science Advances. The authors are University of Minnesota Department of Electrical and Computer Engineering Associate Professor Mo Li, graduate student Li He, and postdoctoral associate Huan Li.

Torque, in the context of light, stems from the spin angular momentum of photons (particles of light), and its measurement is mechanical proof of the quantum nature of light. Although such measurements have been performed in much larger scale systems, the latest results were achieved within a micrometer-sized waveguide—a thin wire that guides light—and demonstrated the use of optical torque to induce rotational motion in a microscale mechanical device.

### *Polarized light and optical torque*

Light is an electromagnetic wave, and its electric field is free to oscillate in any direction. This is called the polarization of light. Your polarizing sunglasses and the goggles you wear to see 3D movies work by using the polarization properties of light.

In a type of polarization state called circular polarization, the electric field of light rotates in a circle because of which the photons have spin angular momentum.

Theory suggests that such spin angular momentum will lead to a mechanical torque on the objects that interact with the circularly polarized light.

While optical forces such as radiation pressure have been studied and harnessed for a while, angular momentum and the force it induces, optical torque, have remained relatively unexplored. Polarization of light plays a critical role in optical communication. Each time the state of polarization changes, photons exchange angular momentum with the device thereby inducing an optical torque.

Measurement and exploitation of angular momentum and the resulting optical torque could give scientists new insights into controlling and manipulating light for new technologies.

To provide some historical context to the work carried out by Professor Mo Li and his team, consider this: the angular momentum of light was first measured in the mid-1930s (during the dawn of the quantum theory of light) by Richard Beth of Princeton University and Worcester Polytechnic Institute. His experiment measured optical torque and confirmed what had been thus far theoretically predicted: photons can have angular momentum. He set up his experiment to measure spin angular momentum of photons in high vacuum, with measurements based on the rotation of a two-inch diameter wave plate—a device that can alter the polarization state of light passing through it. As a testament to the technical difficulty of setting up the experiment, further experiments to measure optical torque and angular momentum have been few and far between.

## *The measurement of angular momentum and optical torque*

Professor Mo Li and his team fabricated an integrated optomechanical device on a silicon chip, with the core element of the device being a waveguide, measuring only 400 nm wide and 340 nm high (unlike the two inch diameter wave plate Beth used), suspended like a string from the substrate. The rectangular cross-section of the waveguide causes the light with horizontal polarization to travel slower than light with vertical polarization. Such an effect is called birefringence, and in this particular case is caused by the geometry of the waveguide rather than the material of the waveguide.

The waveguide works in the same way as a wave plate to change the polarization state of light. When circularly-polarized light is sent into such a waveguide, its polarization state continues to change as it propagates in the waveguide and consequently, the photons exchange spin angular momentum with the waveguide.

"Controlling polarization is critical for modern optical communication. We know from theory that when polarization is changed in an optical fiber or a silicon waveguide, a torque is applied on them," said Huan Li. "The mechanical effect is that the waveguide is twisted [by light] by a very tiny amount that has not been previously measured."

To measure this twisting caused by light, a small silicon beam inscribed with a high quality optical cavity is attached to the waveguide. This provides high measurement sensitivity to the rotation of the beam and the waveguide.

The silicon beam is like the board of a seesaw and the waveguide is like the shaft in the center. When light twists the shaft, the latter rotates and the seesaw tilts, and this is detected by the optical cavity. By changing the polarization of input light periodically, Professor Mo Li's team observed that the nanobeam rotated periodically as well, revealing the optical torque applied on the waveguide.

"From the measurement results, we were able to calculate the spin angular momentum carried by a single photon, which equals to the fundamental Planck constant multiplied by a factor that can be controlled by the waveguide geometry," said Li He. "Our experiment reveals the quantum mechanical property of light on a chip."

For Professor Mo Li and his team, it is exciting that their experiment provides the first unambiguous measurement of the spin angular momentum of photons and the optical torque generated in an integrated photonic device. The result of their experiment also demonstrates that optical torque is influenced by the geometric birefringence, in addition to the material of the waveguide. Also, since the angular momentum of photons is independent of the frequency of light (frequency is what gives light its different colors), the effect of optical torque is the same over the spectral band.

In an age where the power of light is being harnessed for a variety of different applications ranging from medicine to communication systems, exploring the characteristics and resulting effects of photons can be of far reaching impact for scientific devices, military technology, infrastructure, and consumer devices. [14]

## Researchers make better sense of incoherent light

One of the differences between lasers and desk lamps is that laser light is spatially coherent, meaning the peaks and valleys of the light waves are correlated with each other. The jumbled, uncorrelated waves coming from a desk lamp, on the other hand, are often said to be incoherent.

That's a bit of a misnomer, however. In theory, virtually all light—even "incoherent" light—can have a high degree of spatial coherence. But detecting that coherence requires probing light at extremely small length scales that cannot be accessed using traditional techniques.

Now, researchers in the lab of Domenico Pacifici, professor in Brown University's School of Engineering, have found a way to detect spatial coherence in light beams at the scale of a few hundred nanometers—a much smaller scale than has ever been possible. The research provides the first experimental verification of optical coherence theory at the nanoscale.

"There's a very small length scale at which light that's often said to be incoherent behaves coherently, but we've lacked experimental techniques to quantify it," said Drew Morrill, lead author of an article describing the new research. "That degree of coherence contains meaningful information we can now access, which could be useful in characterizing light sources and potentially for new imaging and microscopy techniques."

Morrill, now a graduate student at the University of Colorado, performed the work as an undergraduate at Brown. The research paper, coauthored with Pacifici and Brown postdoctoral scholar Dongfang Li, is published in Nature Photonics.

Traditional methods for testing the extent to which light is spatially coherent involve devices that can split the wavefront of a light beam. The most famous of these is the Young interferometer, also known as the double slit experiment. The experiment consists of a light source aimed at a detector screen, with an opaque barrier between the two. The barrier has two small slits in it, allowing two rays of light to pass through. As the two rays emerge from the slits, some of the light waves are bent toward each other, causing them to recombine. Recombining waves that are coherent will create an interference pattern—a series of light and dark patches—on the detector screen. By measuring the contrast of those light and dark patches, researchers can quantify the light's coherence.

The problem is that for light sources with very low spatial coherence, the double slit experiment doesn't work as well because the length scales at which the interference patterns appear is very small. Producing interference over small length scales requires the two slits to be placed very close together. But when the distance between the two slits gets close to of the wavelength of the light shown upon them, the experiment breaks down. The interferometer can no longer split and recombine the beam properly to look for interference.

"The interference fringes are smeared out, making it difficult to quantify the degree of coherence," Morrill said. "But if you could get around the fundamental limitations of the double slit experiment, theoretically you should be able to see those fringes."

To get around those limitations, the researchers employed a different kind of interferometer that makes use of plasmonics, the interaction between light and electrons in a metal. Instead of two slits, the plasmonic interferometer has a slit and a groove in a surface made of silver. Light hitting the groove creates a surface plasmon polariton (SPP), a density wave of electrons moving across the silver surface. The SPP propagates toward the slit, where it recombines with the light going through the slit. Because the SPP is related to the original beam of light but has a smaller wavelength, and because it diffracts at a 90-degree angle toward the slit, the groove and slit in the plasmonic interferometer can be placed closer together than the two slits in the Young interferometer.

The researchers amassed hundreds of these tiny interferometers, designed and fabricated with nanometric precision, on a microchip. They used that chip to the measure coherence lengths of a broadband xenon lamp for hundreds of wavelengths across the visible spectrum. For blue-green light, measured coherence lengths dropped as low as 330 nanometers—smaller than the 500 nanometer incident wavelength of the light source.

The results are the first experimental confirmation of coherence theory at or below the wavelength of light.

"That was a really exciting result," Morrill said. "Without experimental verification, we really didn't know if these equations held up for these small scales, but it turns out that they do."

In terms of potential applications, the plasmonic chip could help manufacturers of light sources for microscopy, holography and other applications to better characterize their light sources. The integration of the interferometers on a single chip makes the processes of characterizing a light source quick and easy.

"You can just record the degree of spatial coherence in a single snapshot by taking a picture of the light intensity through the densely spaced plasmonic interferometers, which only takes a few seconds," said Li, who led the fabrication of the meter.

"We're providing scientists with a new tool to quantify the degree of coherence of light at a length scale that hadn't been possible before," Pacifici said. [13]

## Physicists discover 'smoke rings' made of laser light

Most basic physics textbooks describe laser light in fairly simple terms: a beam travels directly from one point to another and, unless it strikes a mirror or other reflective surface, will continue traveling along an arrow-straight path, gradually expanding in size due to the wave nature of light. But these basic rules go out the window with high-intensity laser light.

Powerful laser beams, given the right conditions, will act as their own lenses and "self-focus" into a tighter, even more intense beam. University of Maryland physicists have discovered that these self-focused laser pulses also generate violent swirls of optical energy that strongly resemble smoke rings. In these donut-shaped light structures, known as "spatiotemporal optical vortices," the light energy flows through the inside of the ring and then loops back around the outside.

The vortices travel along with the laser pulse at the speed of light and control the energy flow around it. The newly discovered optical structures are described in the September 9, 2016 issue of the journal Physical Review X.

The researchers named the laser smoke rings "spatiotemporal optical vortices," or STOVs. The light structures are ubiquitous and easily created with any powerful laser, given the right conditions. The team strongly suspects that STOVs could explain decades' worth of anomalous results and unexplained effects in the field of high-intensity laser research.

"Lasers have been researched for decades, but it turns out that STOVs were under our noses the whole time," said Howard Milchberg, professor of physics and electrical and computer engineering at UMD and senior author of the research paper, who also has an appointment at the UMD Institute for Research in Electronics and Applied Physics (IREAP). "This is a robust, spontaneous feature that's always there. This phenomenon underlies so much that's been done in our field for the past 30-some years."

More conventional spatial optical vortices are well-known from prior research—chief among them "orbital angular momentum" (OAM) vortices, where light energy circulates around the beam propagation direction much like water rotates around a drain as it empties from a washbasin. Because these vortices can influence the shape of the central beam, they have proven useful for advanced applications such as high-resolution microscopy.

Spatiotemporal optical vortices, or STOVs (thin, gray ringlike objects), are newly described three-dimensional light structures that strongly resemble smoke rings. Unlike other laser vortices, STOVs are time dynamic, which means that they travel along with the central laser pulse. Compared to other laser vortices, STOVs could prove more broadly useful for engineering applications.

"Conventional optical vortices have been studied since the late 1990s as a way to improve telecommunications, microscopy and other applications. These vortices allow you to control what gets illuminated and what doesn't, by creating small structures in the light itself," said the paper's lead author Nihal Jhajj, a physics graduate student who conducted the research at IREAP.

"The smoke ring vortices we discovered may have even broader applications than previously known optical vortices, because they are time dynamic, meaning that they move along with the beam instead of remaining stationary," Jhajj added. "This means that the rings may be useful for manipulating particles moving near the speed of light."

Jhajj and Milchberg acknowledge that much more work needs to be done to understand STOVs, including their physical and theoretical implications. But they are particularly excited for new opportunities that will arise in basic laser research following their discovery of STOVs.

"All the evidence we've seen suggests that STOVs are universal," Jhajj said. "Now that we know what to look for, we think that looking at a high-intensity laser pulse propagating through a medium and not seeing STOVs would be a lot like looking at a river and not seeing eddies and currents."

Eventually, STOVs might have useful real-world applications, like their more conventional counterparts. For example, OAM vortices have been used in the design of more powerful stimulated emission depletion (STED) microscopes. STED microscopes are capable of much higher resolution than traditional confocal microscopes, in part due to the precise illumination offered by optical vortices.

With the potential to travel with the central beam at the speed of light, STOVs could have as-yet unforeseen advantages in technological applications, including the potential to expand the effective bandwidth of fiber-optic communication lines.

"A STOV is not just a spectator to the laser beam, like an angel's halo," explained Milchberg, noting the ability of STOVs to control the central beam's shape and energy flow. "It is more like an electrified angel's halo, with energy shooting back and forth between the halo and the angel's head. We're all very excited to see where this discovery will take us in the future." [12]

## Electrons fingerprint the fastest laser pulses

Analyzing ultrafast chemical processes requires ultrafast lasers—light pulses lasting for mere attoseconds (10-18 second)—to act as a "stop-motion" strobe camera. Physicists at the University of Nebraska-Lincoln are analyzing how ultrafast laser pulses interact with matter. Their study of how two attosecond laser pulses would interact with a helium atom produced an electron momentum distribution that displays an unexpected two-armed vortex pattern, resembling a spiral galaxy.

Attosecond-duration laser pulses provide a new tool with the potential to provide key insights on ultrafast chemical processes and ultimately to control processes that underlie energy-relevant technologies, such as solar energy conversion and catalysis. But before this new tool can meet its full potential, the pulses themselves and their fundamental interactions with matter must be understood. In this case, the researchers reveal vortex patterns produced by attosecond laser pulses can serve as an excellent diagnostic tool for characterizing the electron-manipulating laser pulses. For example, the pattern can be used to determine the intensity of the pulses and the time delay between them.

When interrogating matter with a laser pulse, the duration of the pulse plays a major role in determining the information that can be acquired. In general, the process that is being studied must occur on the same time scale as the laser pulse. For this reason, chemical dynamics processes, which often occur on the femtosecond-to-attosecond time scale, are difficult to study. Recent technological developments are beginning to make attosecond laser pulses a reality, but a great deal of mystery still surrounds the processes that these laser pulses could unveil. Scientists will often use computer simulations, based on quantum mechanical principles, to predict the ultrafast laser interactions they seek to replicate experimentally.

Physicists at the University of Nebraska-Lincoln have taken this approach and simulated the interaction of a helium atom with two time-delayed attosecond laser pulses of opposite circular polarization. The resulting electron momentum distribution displays an unexpected two-armed vortex pattern. The team's first pulse of circularly polarized light rotated in one direction, with the second rotating the opposite way. These orientations dictate whether the resulting spiral pattern appears to swirl left or right. The time delay between the pulses determines the number of windings of the two spiral arms, whereas the duration of the pulses corresponds to the width of the arms. This pattern is significant because it has been observed previously in the interaction of laser beams, but never with electrons. The similarity of the vortex pattern highlights the wave-particle duality of the electron, which describes how it behaves both as a particle and as a wave.

Additionally, the discovery of the vortex pattern has many potential practical applications. Due to the extreme sensitivity of the vortex pattern to the time delay between the two pulses, analyzing the pattern could help characterize the time delay and intensity of attosecond laser pulses. Similarly, the vortex pattern could be used as a "stopwatch" to determine the duration of ultrafast processes. Also, the ability to produce a specific momentum pattern with this interaction demonstrates a new way to control electron motion with laser pulses. [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]

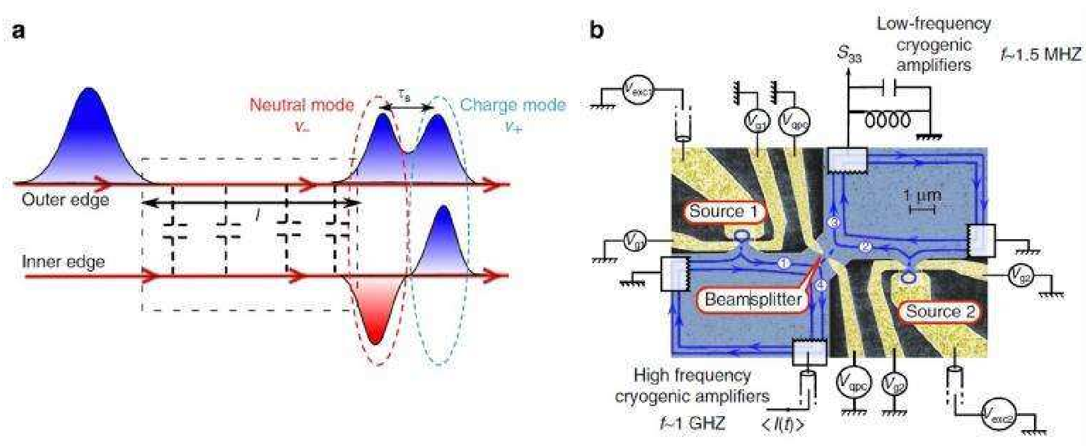
## When an electron splits in two

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

(2) $I = n^2 I_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

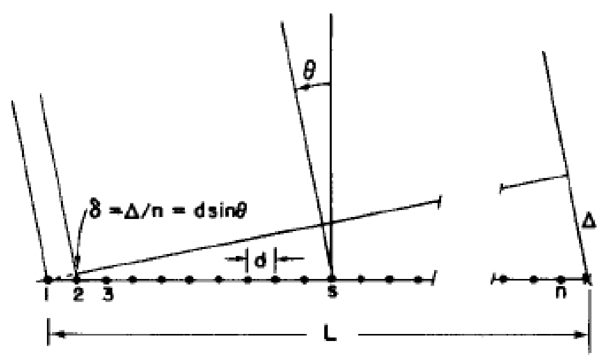



Fig. 30–3. A linear array of $n$ equal oscillators, driven with phases $\alpha_s = s\alpha$.

Figure 1.) A linear array of n equal oscillators

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

So

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

and we get m-order beam if $\lambda$ less than d. [6]

If d less than $\lambda$ we get only zero-order one centered at $\theta = 0$. Of course, there is also a beam in the opposite direction. The right chooses of d and $\lambda$ 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 ($\lambda$), Planck's law is written as:

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

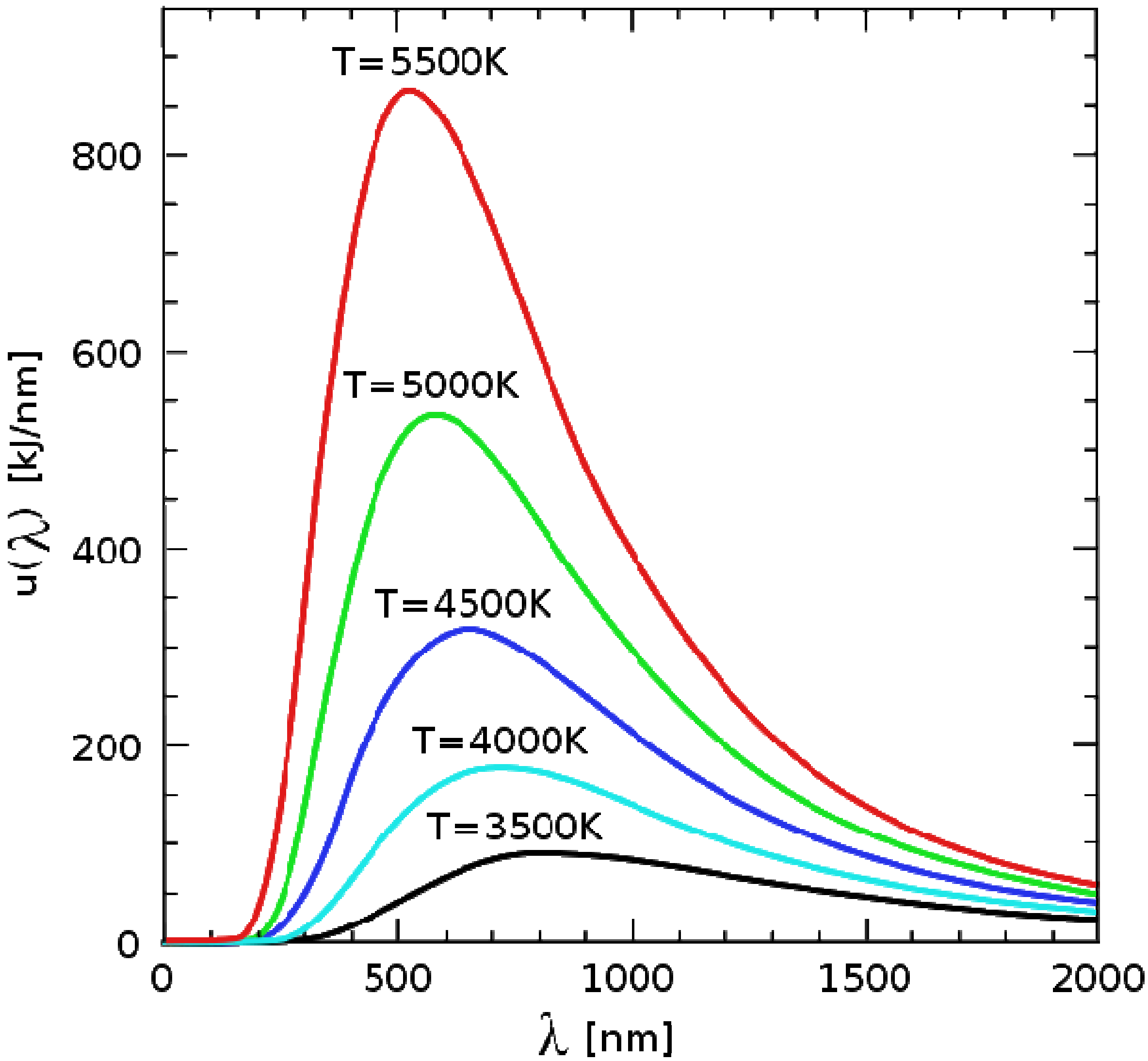



Figure 2. The distribution law for different T temperatures

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

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

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

where $\lambda_{max}$ is the peak wavelength, $T$ is the absolute temperature of the black body, and $b$ is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977685(51) \times 10^{-3}$ 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 $\nu$, wavelength *λ*, and speed of light *c* are related by *λν* = *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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