Quantized Anomalous Hall Effect

The quantum anomalous Hall (QAH) effect can combine topology and magnetism to produce precisely quantized Hall resistance at zero magnetic field (an environment carefully screened from magnetic fields). [12]

Using ultracold atoms trapped in a periodically modulated two-dimensional superlattice potential, the scientists could observe a dynamical version of a novel type of quantum Hall effect that is predicted to occur in four-dimensional systems. [11]

Using two types of "designer" quantum dots, researchers are creating double-pane solar windows that generate electricity with greater efficiency and create shading and insulation for good measure. [10]

Nearly 75 years ago, Nobel Prize-winning physicist Erwin Schrödinger wondered if the mysterious world of quantum mechanics played a role in biology. A recent finding by Northwestern University's Prem Kumar adds further evidence that the answer might be yes. [9]
A UNSW Australia-led team of researchers has discovered how algae that survive in very low levels of light are able to switch on and off a weird quantum phenomenon that occurs during photosynthesis. [8]

This paper contains the review of quantum entanglement investigations in living systems, and in the quantum mechanically modeled photoactive prebiotic kernel systems. [7]

The human body is a constant flux of thousands of chemical/biological interactions and processes connecting molecules, cells, organs, and fluids, throughout the brain, body, and nervous system. Up until recently it was thought that all these interactions operated in a linear sequence, passing on information much like a runner passing the baton to the next runner. However, the latest findings in quantum biology and biophysics have discovered that there is in fact a tremendous degree of coherence within all living systems.

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.

The Planck Distribution Law of the electromagnetic oscillators explains the electron/proton mass rate and the Weak and Strong Interactions by the diffraction patterns. The Weak Interaction changes the diffraction patterns by moving the electric charge from one side to the other side of the diffraction pattern, which violates the CP and Time reversal symmetry.

The diffraction patterns and the locality of the self-maintaining electromagnetic potential explains also the Quantum Entanglement, giving it as a natural part of the Relativistic Quantum Theory and making possible to understand the Quantum Biology.

Contents

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Preface

We define our modeled self-assembled supramolecular photoactive centers, composed of one or more sensitizer molecules, precursors of fatty acids and a number of water molecules, as a photoactive prebiotic kernel system. [7]

The human body is a constant flux of thousands of chemical/biological interactions and processes connecting molecules, cells, organs, and fluids, throughout the brain, body, and nervous system. Up until recently it was thought that all these interactions operated in a linear sequence, passing on information much like a runner passing the baton to the next runner. However, the latest findings in quantum biology and biophysics have discovered that there is in fact a tremendous degree of coherence within all living systems. [5]

Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently – instead, a quantum state may be given for the system as a whole. [4]

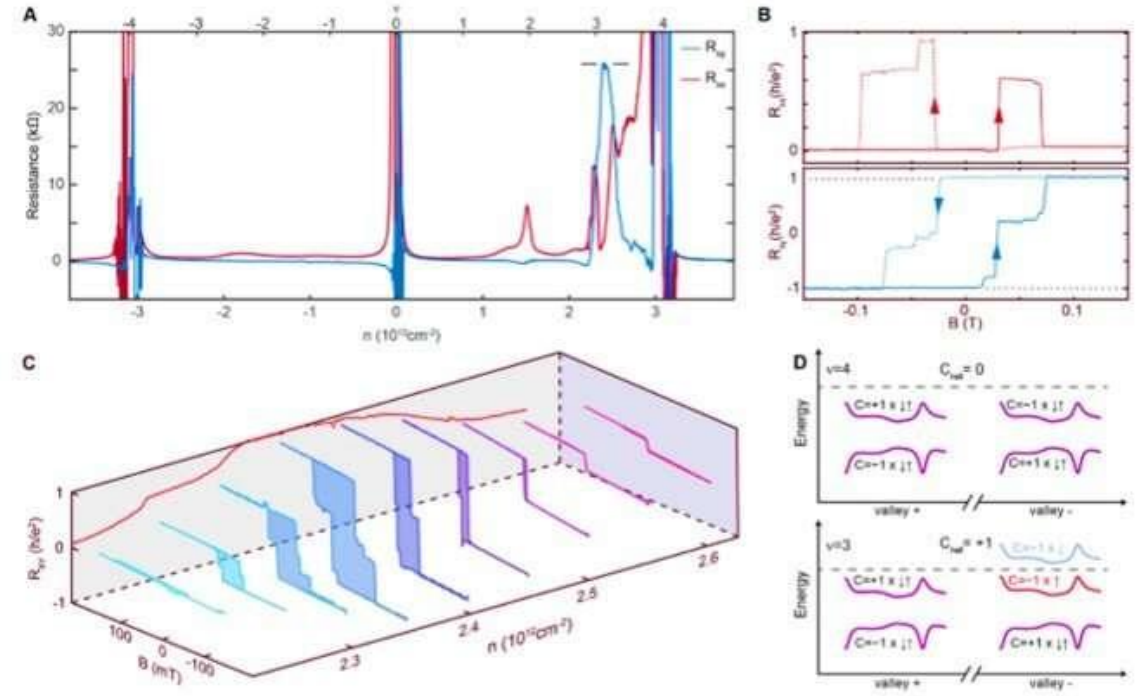
I think that we have a simple bridge between the classical and quantum mechanics by understanding the Heisenberg Uncertainty Relations. It makes clear that the particles are not point like but have a dx and dp uncertainty.

Intrinsic quantized anomalous Hall effect in a moiré heterostructure

The quantum anomalous Hall (QAH) effect can combine topology and magnetism to produce precisely quantized Hall resistance at zero magnetic field (an environment carefully screened from magnetic fields). In a recent report on *Science*, M. Serlin and an interdisciplinary research team in the Department of Physics, National Institute of Materials Science and the Kavli Institute for Theoretical Physics in the U.S. and Japan detailed the observation of a QAH effect in twisted bilayer graphene aligned to hexagonal boron nitride. They drove the effect via intrinsic strong interactions, which polarized the electrons into a single spin and valley resolved moiré miniband (interference pattern).

When a magnetic field is applied at right angles to the current flow in a thin film, an electric field known as the Hall effect can be generated mutually perpendicular to the current and the magnetic field. An anomalous Hall effect requires combined magnetic polarization and spin-orbit coupling in the absence of an external magnetic field (hence the anomaly). When the anomalous Hall effect is quantized, it is known as the quantum anomalous Hall effect. In contrast to magnetically doped systems, the transport energy map measured by Serlin et al. was larger than the Curie temperature for magnetic ordering. Electrical currents as small as 1 nA could controllably switch the magnetic order between states of opposite polarization to form an electrically rewritable magnetic memory.

Physicists and materials scientists can classify two-dimensional insulators using the topology of their filled energy bands. In the absence of time reversal symmetry (conservation of entropy), nontrivial band topology can manifest experimentally as quantized Hall conductivity. Researchers are motivated by fundamental questions on the nature of topological phase transitions and their possible applications in resistance metrology and in topological quantum computing. They have devoted significant efforts to engineer quantized anomalous Hall effects with topologically protected quantized resistance in the absence of an applied magnetic field. Scientists had only thus far observed QAH effects in a narrow class of materials containing doped transition materials. The dopant magnetic moments in these materials broke time reversal symmetry, combined with the strongly spin-orbit coupled electronic structures to produce topologically nontrivial Chern bands (energy bands).

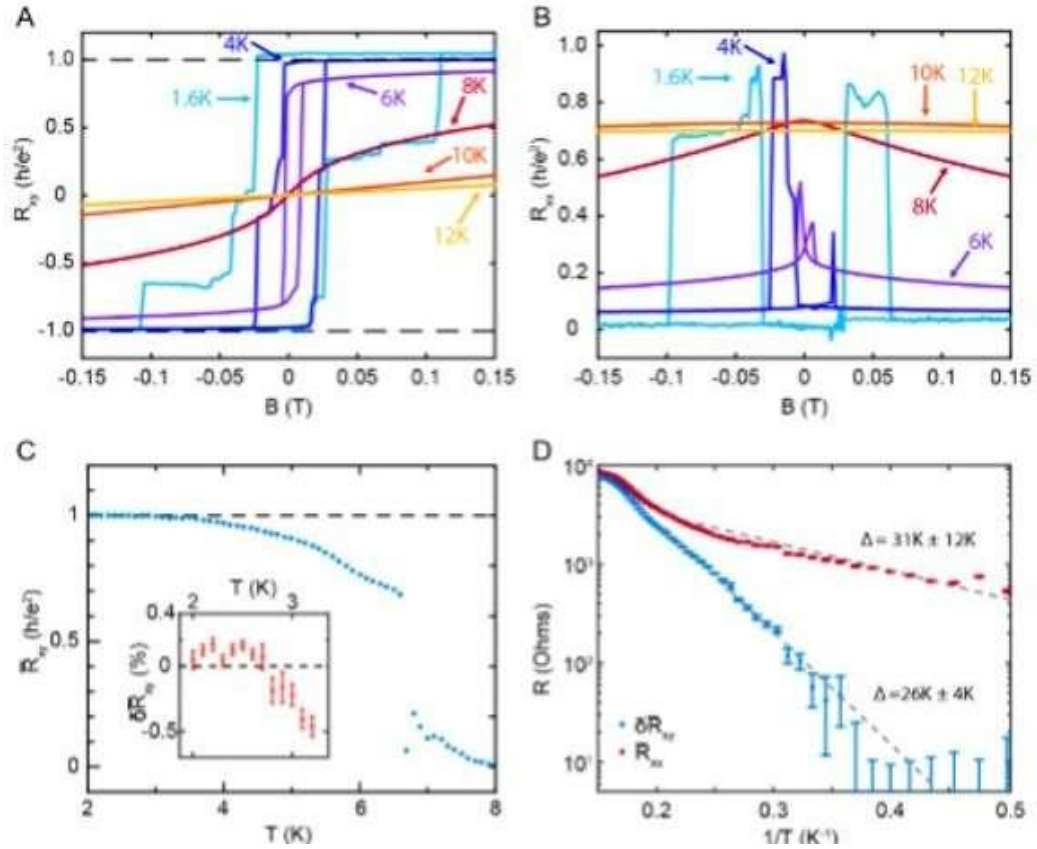


Quantized anomalous Hall effect in twisted bilayer graphene at 1.6 K. (A) Longitudinal resistance Rxx and Hall resistance Rxy as a function of carrier density n at 150 mT. Rxy reaches h/e2 and Rxx approaches zero near ν = 3. Data are corrected for mixing of Rxx and Rxy components by symmetrizing with respect to magnetic field at B = ±150 mT. (B) Longitudinal resistance Rxx and Hall resistance Rxy measured at n = 2.37 × 10^12 cm−2 as a function of B. Data are corrected for mixing using contact symmetrization. Sweep directions are indicated by arrows. (C) Hall resistance Rxy as a function of magnetic field B and density n. Hysteresis loop areas are shaded for clarity. The rear wall shows field-training symmetrized values of Rxy at B = 0. Rxy(0) becomes nonzero when ferromagnetism appears and reaches a plateau of h/e2 near a density of n = 2.37 × 10^12 cm−2. (D) Schematic band structure at full filling of a moiré unit cell (ν = 4) and ν = 3. The net Chern number Cnet ≠ 0 at ν = 3. Credit: Science, doi: 10.1126/science.aay5533.

The performance of these materials is, however, limited by the inhomogeneous distribution of magnetic dopants (additives), leading to structural, charge and magnetic disorder at the microscale. The resulting quantization therefore occurs at temperatures that are approximately an order of magnitude smaller than the magnetic ordering temperature. To engineer intrinsic quantum anomalous Hall effects, moiré graphene heterostructures provide two essential ingredients; topological bands and strong correlations. For instance, in hexagonal boron nitride (hBN) and twisted multilayer graphene, moiré patterns generically produce bands with finite Chern number, where time reversal symmetry of the single particle band structure can be enforced by canceling Chern numbers in opposite graphene valleys. For example, in specific heterostructures such as twisted bilayer graphene (tBLG) with an interlayer twist angle and rhombohedral graphene aligned to hBN, the bandwidth of Chern bands can be made exceptionally small. Scientists have demonstrated states of magnetic hysteresis (deviation from the theoretical value) relative to time-reversal

symmetry breaking in tBLG and hBN heterostructures to show large anomalous Hall effects.

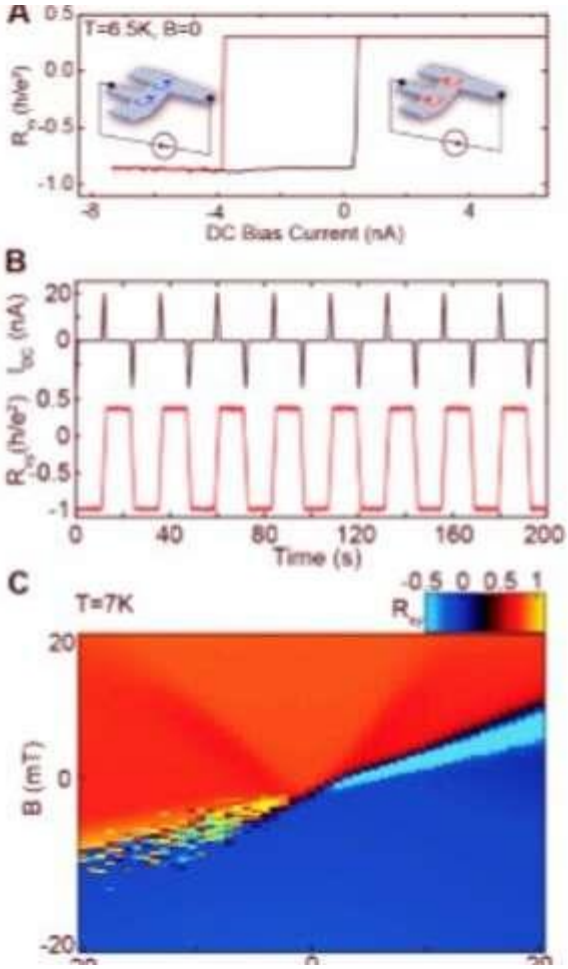
In the present work, Serlin et al. observed a QAH (quantum anomalous Hall) effect showing a robust magnetic field quantization in a flat band tBLG (twisted bilayer graphene) sample aligned to hBN (hexagonal boron nitride). They described the electronic structure of the flat-band tBLG via two distinct bands per spin and valley projection isolated from higher energy dispersive bands by an energy gap. The flat bands had a total capacity of eight electrons per unit cell, the research team defined the band filling factor as $\nu = nA_m$, where n equaled the electron density and A_m equaled an area of 130 nm^2 within the moiré unit cell.



Temperature dependence of the quantum anomalous Hall effect. (A) Rxy and (B) Rxx as a function of B measured at various temperatures for n = 2.37 × 1012 cm−2. Rxx and Rxy mixing was corrected using contact symmetrization. (C) Temperature dependence of the field-training symmetrized resistance xy R at B = 0, as described in the main text. The Curie temperature was determined to be TC ≈ 7.5(.5) K using an Arrott plot analysis. Inset: detailed low temperature dependence of the deviation of xy R from the quantized value at B = 0. Error bars are the standard error derived from 11 consecutive measurements. xy R saturates below ≈3 K to a value determined by averaging the points between 2 and 2.7 K. (D) Arrhenius plots of field training symmetrized resistances at B = 0. Dotted lines denote representative activation fits. Systematic treatment of uncertainty arising from the absence of a single activated regime gives Δ = 31 ± 11 K and 26 ± 4 K. Credit: Science, doi: 10.1126/science.aay5533

The team recorded the longitudinal and Hall resistance at a magnetic field (B) of 150 mT and temperature (T) of 1.6 K, as a function of charge density across the entire flat band. They observed the Hall resistivity to be hysteretic (lagging in response to changing conditions) and the results showed a QAH state stabilized by spontaneously broken time reversal symmetry. The scientists only observed the quantized response for a particular choice of contacts at a specific compartment of the device. The observed magnetism arose from the 2-D nature of the graphene bands. Serlin et al. technically aligned the device to one of the hBN layers and based on the observations, predicted the hBN aligned samples to constitute a different class of tBLG devices with distinct phenomenology.

As the temperature of the system increased, the scientists observed a departure from resistance quantization and suppression of hysteresis with the Hall effect to demonstrate linear behavior in the field at 12 K. They observed finite hysteresis up to temperatures of 8 K, consistent with the Curie temperature (T_C = 7.5 K). Thereafter, to quantitatively assess the energy scales associated with the QAH states, the team measured the activation energy at a lower temperature. They noted the activation energy to be several times larger than T_C, in contrast to magnetically doped insulator films where the activations gaps were typically 10 to 50 times smaller than T_C.



Current controlled magnetic switching. (A) Rxy as a function of applied DC current, showing hysteresis as a function of DC current analogous to the response to an applied magnetic field at 6.5 K. Insets: schematic illustrations of current controlled orbital magnetism. (B) Nonvolatile electrical writing and reading of a magnetic bit at T = 6.5 K and B = 0. A succession of 20 nA current pulses of alternating signs controllably reverses the magnetization, which is read out using the Hall resistance. The magnetization state of the bit is stable for at least 103 s (29). (C) Rxy as a function of both DC bias current and magnetic field at 7 K. Opposite directions of DC current preferentially stabilize opposite magnetization states of the bit. Measurements presented in (A to C) are neither field nor Onsager symmetrized, which why there is an offset in Rxy. Credit: Science, doi: 10.1126/science.aay5533

Since the ferromagnetic domains in tBLG can strongly interact with applied current to allow deterministic control within the device for domain polarization with exceptionally small DC currents. In the present work, the applied DC currents drove switching similar to that observed in an applied magnetic field, to produce hysteretic switching between magnetization states. Serlin et al. also obtained deterministic non-volatile electrical writing and reading of a magnetic bit using a succession of 20 nA current pulses to controllably reverse the magnetization, followed by a read-out using the large resulting change in the Hall resistance. The absolute magnitude of the current required to switch the magnetization state of the system approximated 10^{-9} A, considerably smaller than that reported in any previous system.

Based on the results, the team proposed a simple mechanism to explain the observed low-current switching that arose from the interplay of edge state physics and device asymmetry. Accordingly, in a QAH (quantum anomalous Hall) system, an applied current can generate a chemical potential difference between the chiral one-dimensional modes located on opposite sample edges. When the edges have different lengths or velocities, the current favored one of the two domains where the sign and magnitude of the effect was determined according to the device symmetry. In this way, M. Serlin and colleagues noted the observed effect to be generic to all QAH systems and likely to be dominant at low currents in tBLG due to weak pinning of magnetic domains and small device dimensions. The work provides an engineering parameter for electrical control of domain structure, which can be encoded deterministically into the device geometry. [12]

Leaving flatland – quantum Hall physics in 4-D

In literature, the potential existence of extra dimensions was discussed in Edwin Abbott's satirical novel "Flatland: A Romance of Many Dimensions" (1884), portraying the Victorian society in 19th century England as a hierarchical two-dimensional world, incapable of realizing its narrow-mindedness due to its lower-dimensional nature.

In physics, on the other hand, the possibility that our universe comprises more than three spatial dimensions was first proposed in the wake of Albert Einstein's theory of general relativity in the 1920s. Modern string theory – trying to reconcile Einstein's ideas with the laws of quantum mechanics – even postulates up to 10 dimensions.

In a completely different context, an international team of researchers led by Professor Immanuel Bloch (LMU/MPQ) and Professor Oded Zilberberg (ETH Zürich) has now demonstrated a way to observe physical phenomena proposed to exist in higher-dimensional systems in analogous real-world experiments. Using ultracold atoms trapped in a periodically modulated two-dimensional superlattice potential, the scientists could observe a dynamical version of a novel type of quantum Hall effect that is predicted to occur in four-dimensional systems.

The Hall effect occurs when charged particles move in a two-dimensional plane in the presence of a magnetic field. The magnetic field generates a Lorentz force, which deflects the particles in the direction orthogonal to their motion. This manifests in the appearance of a transverse Hall voltage. In 1980, Klaus von Klitzing made the remarkable discovery that at low temperatures and very strong magnetic fields this voltage can only take certain quantized values.

Moreover, these values are identical irrespective of the specific properties of the experimental sample. This astonishing fact was later shown to be related to the topology of the quantum mechanical wave functions describing the behaviour of electrons at such low energies – a seminal work for which David Thouless was awarded the Nobel prize in physics in 2016.

An important prerequisite for the quantum Hall effect turned out to be the two-dimensional geometry of the sample. It can be proven that in general such a phenomenon cannot take place in three-dimensional systems – as exemplified by the fact that the direction transverse to the velocity

of the particles is not defined uniquely in three dimensions. Thus, it was believed that this effect is special to two dimensions.

Yet, 20 years after the initial discovery theoretical physicists postulated that a similar effect could also take place in four-dimensional systems, for which even more remarkable properties including a novel non-linear Hall current were predicted. For a long time, however, this proposal was mostly regarded as a mathematical curiosity – out of reach for actual experiments – despite its far-reaching implications. For example, both topological insulators and Weyl semimetals, two of the most prominent discoveries in condensed matter physics in recent years, can be derived from 4-D quantum Hall models.

In 2013, Oded Zilberberg and collaborators realized that key signatures of the 4-D quantum Hall effect should also be visible in special time-dependent systems in two dimensions, so-called topological charge pumps, which constitute a dynamical version of the higher-dimensional model. This insight generalized an idea, which also goes back to David Thouless. In 1983, Thouless showed that a quantized transport of particles can be generated by periodically modulating a 1D system and that this response is mathematically equivalent to the 2-D quantum Hall effect. Consequently, by combining two such systems in orthogonal directions, it should be possible to observe the non-linear Hall current predicted in 4-D.

This has now been achieved by the group of Immanuel Bloch. At first a cloud of atoms is cooled down close to absolute zero and placed in a 2-D optical lattice. Such an optical lattice is created by interference of retro-reflected laser beams of a certain wavelength along two orthogonal directions. The resulting potential resembles an egg-carton-like "crystal of light", in which the atoms can move. By adding another laser beam with a different wavelength in each direction, a so-called superlattice is created.

The researchers could implement the proposed 2-D topological charge pump by introducing a constant tiny angle between the beams of different wavelength along one axis while at the same time dynamically changing the shape of the potential in the orthogonal direction by slightly shifting the wavelength of the additional laser beam.

When modulating the potential in time, the atoms predominantly move in the direction of the modulation and do so in a quantized way – the linear (i.e. 1D) response corresponding to the 2-D quantum Hall effect as predicted by Thouless. But in addition to this, the Munich team also observed a slight drift in the transverse direction, even though the lattice potential in this direction remains static throughout the experiment. This transverse motion is the equivalent of the non-linear Hall response – the essential feature of the 4-D Hall effect. By carefully monitoring and analyzing at which positions in the superlattice the atoms are located during this process, the scientists could furthermore demonstrate that this motion is quantized, thereby revealing the quantum nature of the Hall effect in 4-D.

The results have now been published in the journal *Nature* ("Exploring 4-D quantum Hall physics with a 2-D topological charge pump") together with complementary work by an American research team, which used photonic structures to study the intricate boundary phenomena that accompany this motion as a result of the 4-D quantum Hall effect.

Together, these papers provide the first experimental glimpse into the physics of higher-dimensional quantum Hall systems, which offer a number of fascinating future prospects. These include fundamental questions for our understanding of the universe like the interplay of quantum correlations and dimensionality, the generation of cosmic magnetic fields and quantum gravity, for which 4-D quantum Hall systems have been proposed as toy models. [11]

Tweaking quantum dots powers-up double-pane solar windows

Using two types of "designer" quantum dots, researchers are creating double-pane solar windows that generate electricity with greater efficiency and create shading and insulation for good measure. It's all made possible by a new window architecture which utilizes two different layers of low-cost quantum dots tuned to absorb different parts of the solar spectrum.

"Because of the the strong performance we can achieve with low-cost, solution-processable materials, these quantum-dot-based double-pane windows and even more complex luminescent solar concentrators offer a new way to bring down the cost of solar electricity," said lead researcher Victor Klimov. "The approach complements existing photovoltaic technology by adding high-efficiency sunlight collectors to existing solar panels or integrating them as semitransparent windows into a building's architecture."

The key to this advance is "solar-spectrum splitting," which allows one to process separately higher- and lower-energy solar photons. The higher-energy photons can generate a higher photovoltage, which could boost the overall power output. This approach also improves the photocurrent as the dots used in the front layer are virtually "reabsorption free."

To achieve this, the Los Alamos team incorporates into quantum dots ions of manganese that serve as highly emissive impurities. Light absorbed by the quantum dots activates these impurities. Following activation, the manganese ions emit light at energies below the quantum-dot absorption onset. This trick allows for almost complete elimination of losses due to self-absorption by the quantum dots.

To transform a window into a tandem luminescent sunlight collector, the Los Alamos team deposits a layer of highly emissive manganese-doped quantum dots onto the surface of the front glass pane and a layer of copper indium selenide quantum dots onto the surface of the back pane. The front layer absorbs the blue and ultraviolet portions of the solar spectrum, while the rest of the spectrum is picked up by the bottom layer.

Following absorption, the dot re-emits a photon at a longer wavelength, and then the re-emitted light is guided by total internal reflection to the glass edges of the window. There, solar cells integrated into the window frame collect the light and convert it to electricty.

Experiment demonstrates quantum mechanical effects from biological systems

Nearly 75 years ago, Nobel Prize-winning physicist Erwin Schrödinger wondered if the mysterious world of quantum mechanics played a role in biology. A recent finding by Northwestern University's Prem Kumar adds further evidence that the answer might be yes.

Kumar and his team have, for the first time, created quantum entanglement from a biological system. This finding could advance scientists' fundamental understanding of biology and potentially open doors to exploit biological tools to enable new functions by harnessing quantum mechanics.

"Can we apply quantum tools to learn about biology?" said Kumar, professor of electrical engineering and computer science in Northwestern's McCormick School of Engineering and of physics and astronomy in the Weinberg College of Arts and Sciences. "People have asked this question for many, many years—dating back to the dawn of quantum mechanics. The reason we are interested in these new quantum states is because they allow applications that are otherwise impossible."

Partially supported by the Defense Advanced Research Projects Agency, the research was published Dec. 5 in *Nature Communications*.

Quantum entanglement is one of quantum mechanics' most mystifying phenomena. When two particles—such as atoms, photons, or electrons—are entangled, they experience an inexplicable link that is maintained even if the particles are on opposite sides of the universe. While entangled, the particles' behavior is tied one another. If one particle is found spinning in one direction, for example, then the other particle instantaneously changes its spin in a corresponding manner dictated by the entanglement. Researchers, including Kumar, have been interested in harnessing quantum entanglement for several applications, including quantum communications. Because the particles can communicate without wires or cables, they could be used to send secure messages or help build an extremely fast "quantum Internet."

"Researchers have been trying to entangle a larger and larger set of atoms or photons to develop substrates on which to design and build a quantum machine," Kumar said. "My laboratory is asking if we can build these machines on a biological substrate."

In the study, Kumar's team used green fluorescent proteins, which are responsible for bioluminescence and commonly used in biomedical research. The team attempted to entangle the photons generated from the fluorescing molecules within the algae's barrel-shaped protein structure by exposing them to spontaneous four-wave mixing, a process in which multiple wavelengths interact with one another to produce new wavelengths.

Through a series of these experiments, Kumar and his team successfully demonstrated a type of entanglement, called polarization entanglement, between photon pairs. The same feature used to make glasses for viewing 3D movies, polarization is the orientation of oscillations in light waves. A wave can oscillate vertically, horizontally, or at different angles. In Kumar's entangled pairs, the photons' polarizations are entangled, meaning that the oscillation directions of light waves are linked. Kumar also noticed that the barrel-shaped structure surrounding the fluorescing molecules protected the entanglement from being disrupted.

"When I measured the vertical polarization of one particle, we knew it would be the same in the other," he said. "If we measured the horizontal polarization of one particle, we could predict the horizontal polarization in the other particle. We created an entangled state that correlated in all possibilities simultaneously."

Now that they have demonstrated that it's possible to create quantum entanglement from biological particles, next Kumar and his team plan to make a biological substrate of entangled particles, which could be used to build a quantum machine. Then, they will seek to understand if a biological substrate works more efficiently than a synthetic one. [9]

Quantum biology: Algae evolved to switch quantum coherence on and off

A UNSW Australia-led team of researchers has discovered how algae that survive in very low levels of light are able to switch on and off a weird quantum phenomenon that occurs during photosynthesis.

The function in the algae of this quantum effect, known as coherence, remains a mystery, but it is thought it could help them harvest energy from the sun much more efficiently. Working out its role in a living organism could lead to technological advances, such as better organic solar cells and quantum-based electronic devices.

The research is published in the journal Proceedings of the National Academy of Sciences.

It is part of an emerging field called quantum biology, in which evidence is growing that quantum phenomena are operating in nature, not just the laboratory, and may even account for how birds can navigate using the earth's magnetic field.

"We studied tiny single-celled algae called cryptophytes that thrive in the bottom of pools of water, or under thick ice, where very little light reaches them," says senior author, Professor Paul Curmi, of the UNSW School of Physics.

"Most cryptophytes have a light-harvesting system where quantum coherence is present. But we have found a class of cryptophytes where it is switched off because of a genetic mutation that alters the shape of a light-harvesting protein.

"This is a very exciting find. It means we will be able to uncover the role of quantum coherence in photosynthesis by comparing organisms with the two different types of proteins."

In the weird world of quantum physics, a system that is coherent – with all quantum waves in step with each other – can exist in many different states simultaneously, an effect known as superposition. This phenomenon is usually only observed under tightly controlled laboratory conditions.

So the team, which includes Professor Gregory Scholes from the University of Toronto in Canada, was surprised to discover in 2010 that the transfer of energy between molecules in the light harvesting systems from two different cryptophyte species was coherent.

The same effect has been found in green sulphur bacteria that also survive in very low light levels.

"The assumption is that this could increase the efficiency of photosynthesis, allowing the algae and bacteria to exist on almost no light," says Professor Curmi.

"Once a light-harvesting protein has captured sunlight, it needs to get that trapped energy to the reaction centre in the cell as quickly as possible, where the energy is converted into chemical energy for the organism.

"It was assumed the energy gets to the reaction centre in a random fashion, like a drunk staggering home. But quantum coherence would allow the energy to test every possible pathway simultaneously before travelling via the quickest route."

In the new study, the team used x-ray crystallography to work out the crystal structure of the lightharvesting complexes from three different species of cryptophytes.

They found that in two species a genetic mutation has led to the insertion of an extra amino acid that changes the structure of the protein complex, disrupting coherence.

"This shows cryptophytes have evolved an elegant but powerful genetic switch to control coherence and change the mechanisms used for light harvesting," says Professor Curmi.

The next step will be to compare the biology of different cryptophytes, such as whether they inhabit different environmental niches, to work out whether the quantum coherence effect is assisting their survival. [8]

Photoactive Prebiotic Systems

We propose that life first emerged in the form of such minimal photoactive prebiotic kernel systems and later in the process of evolution these photoactive prebiotic kernel systems would have produced fatty acids and covered themselves with fatty acid envelopes to become the minimal cells of the Fatty Acid World. Specifically, we model self-assembling of photoactive prebiotic systems with observed quantum entanglement phenomena. We address the idea that quantum entanglement was important in the first stages of origins of life and evolution of the biospheres because simultaneously excite two prebiotic kernels in the system by appearance of two additional quantum entangled excited states, leading to faster growth and self-replication of minimal living cells. The quantum mechanically modeled possibility of synthesizing artificial self-reproducing quantum entangled prebiotic kernel systems and minimal cells also impacts the possibility of the most probable path of emergence of photocells on the Earth or elsewhere. We also examine the quantum entangled logic gates discovered in the modeled systems composed of two prebiotic kernels. Such logic gates may have application in the destruction of cancer cells or becoming building blocks of new forms of artificial cells including magnetically active ones.

Significance Statement

Our investigated self-assembly of molecules towards supramolecular bioorganic and minimal cellular systems depends on the quantum mechanics laws which induce hydrogen and Van der Waals bindings (Tamulis A, Grigalavicius, M, Orig Life Evol Biosph 41:51-71, 2011).

In the work presented here, quantum entanglement takes the form of a quantum superposition of the active components in synthesized self-assembling and self-replicating living systems. When a quantum calculation of an entangled system is made that causes one photoactive biomolecule of such a pair to take on a definite value (e.g., electron density transfer or electron spin density transfer), the other member of this entangled pair will be found to have taken the appropriately correlated value (e.g., electron density transfer or electron spin density transfer). In our simulations, the separation distance of supramolecular bio systems changes took place during geometry optimization procedures, which mimic real-world intermolecular interaction processes.

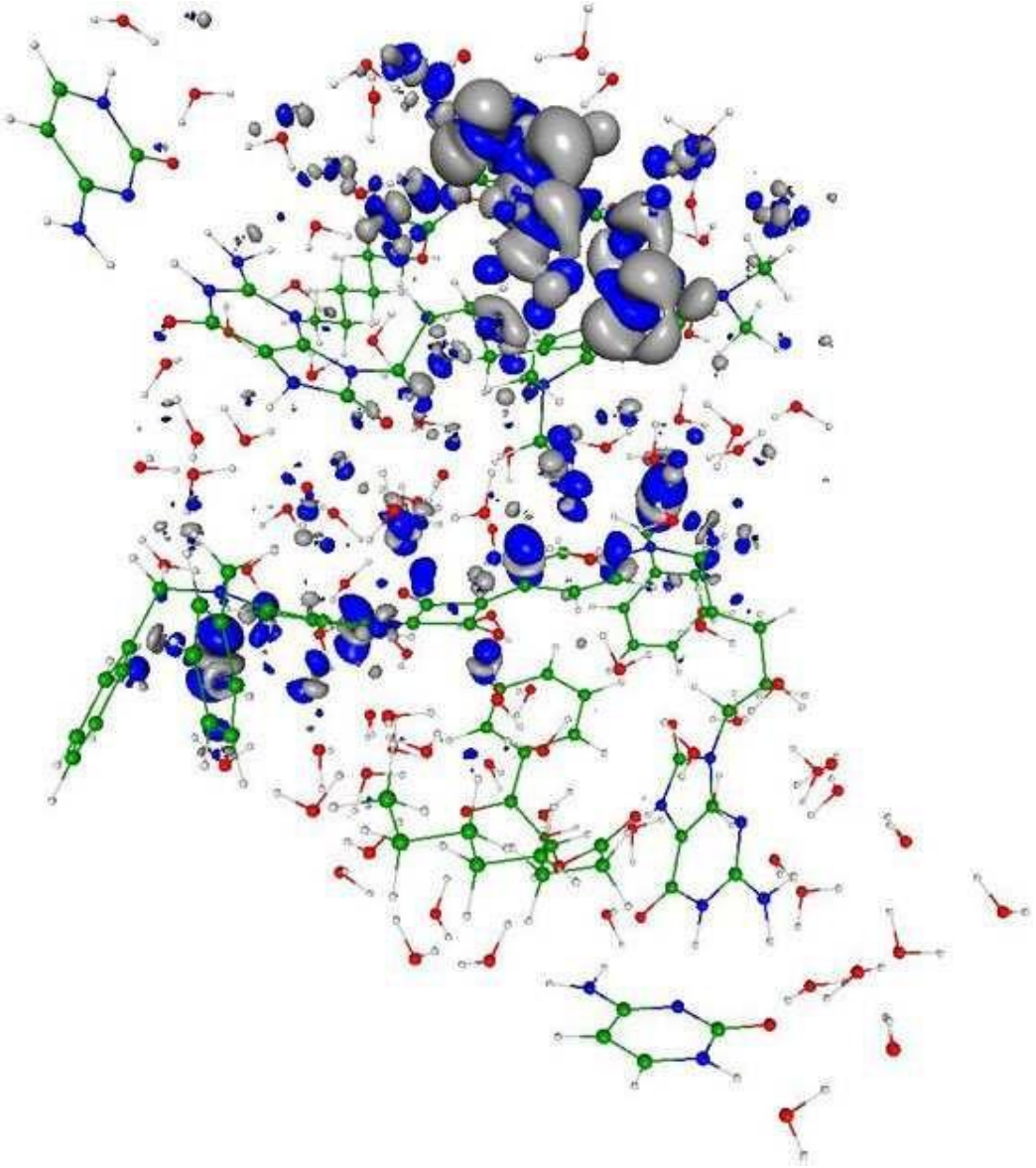
Our discovered phenomenon of the quantum entanglement in the prebiotic systems enhance the photosynthesis in the proposed systems because simultaneously excite two prebiotic kernels in the system by appearance of two additional quantum entangled excited states (Tamulis A, Grigalavicius M, Baltrusaitis J, Orig Life Evol Biosph 43:49-66, 2013; Tamulis A, Grigalavicius M, Krisciukaitis S (2014) , J Comput Theor Nanos, 11, 1597-1608, 2014; Tamulis A, Grigalavicius M, 8:117-140, 2014.). We can propose that quantum entanglement enhanced the emergence of photosynthetic prebiotic kernels and accelerated the evolution of photosynthetic life because of additional absorbed light energy, leading to faster growth and self-replication of minimal living cells.

We can state that: Livings are self-assembled and self-replicating wet and warm stochastically moving supramolecular systems where quantum entanglement can be continuously generated and destroyed by non-equilibrium effects in an environment where no static entanglement exists; quantum entanglement involve the biomolecule inside one living or between other neighboring livings.

This warm quantum coherence is basic for the explanation of DNA stability and for the understanding of brain magnetic orientation during migration in more than 50 species of birds, fishes and insects. Exists experimental evidence for quantum-coherent is used for more efficient light-harvesting in plant photosynthesis. Quantum entanglement exists in supramolecules determining the sense of smell and in the brain neurons microtubules due to quantum vibrations.

In the work presented here, we started to design and quantum mechanical investigations of the molecular logical devices which are useful for construction of nano medicine biorobots against the molecular diseases such a cancer tumors, and against the new kinds of synthesized microorganisms and nano guns.

Figure legend



You can see in the enclosed figure the quantum entanglement phenomenon in the closely selfassembled two synthesized protocell system due to the photo excited electron charge transfer from one protocell to another that leads to closer self-assembly and exchange of energy and information.

Visualization of the electron charge tunneling associated with the 6th (467.3 nm) excited state. The transition is mainly from squarine molecule of the first protocell situated in the bottom of this bi cellular system to precursor of fatty acid (pFA) molecule of the second subsystem (in the top) and little from the 1,4-bis(N,N-dimethylamino)naphthalene molecule (in the top-right) to the same pFA molecule of the second subsystem (in the top). The electron cloud hole is indicated by the dark blue color while the transferred electron cloud location is designated by the gray color.

As a result, these nonlinear quantum interactions compressed the overall molecular system resulting in a smaller gap between the HOMO and LUMO electron energy levels which allows enhanced tunneling of photo excited electrons from the sensitizer squarine and (1,4-bis(N,Ndimethylamino)naphthalene) to the pFA molecule resulting in its cleavage. The new fatty acid joins the existing minimal cell thus increasing it in size. After reaching some critical size, the minimal cell should divide (i.e. self-replicate) into two separate smaller minimal cells. [7]

Quantum Biology

Researchers have long suspected that something unusual is afoot in photosynthesis. Particles of light called photons, streaming down from the Sun; arrive randomly at the chlorophyll molecules and other light-absorbing 'antenna' pigments that cluster inside the cells of every leaf, and within every photosynthetic bacterium. But once the photons' energy is deposited, it doesn't stay random. Somehow, it gets channeled into a steady flow towards the cell's photosynthetic reaction centre, which can then use it at maximum efficiency to convert carbon dioxide into sugars. Quantum coherence in photosynthesis seems to be beneficial to the organisms using it. But did their ability to exploit quantum effects evolve through natural selection? Or is quantum coherence just an accidental side effect of the way certain molecules are structured? [6]

Quantum Consciousness

Extensive scientific investigation has found that a form of quantum coherence operates within living biological systems through what is known as biological excitations and biophoton emission. What this means is that metabolic energy is stored as a form of electromechanical and electromagnetic excitations. These coherent excitations are considered responsible for generating and maintaining long-range order via the transformation of energy and very weak electromagnetic signals. After nearly twenty years of experimental research, Fritz-Albert Popp put forward the hypothesis that biophotons are emitted from a coherent electrodynamics field within the living system.

What this means is that each living cell is giving off, or resonating, a biophoton field of coherent energy. If each cell is emitting this field, then the whole living system is, in effect, a resonating field-a ubiquitous nonlocal field. And since biophotons are the entities through which the living system communicates, there is near-instantaneous intercommunication throughout. And this, claims Popp, is the basis for coherent biological organization -- referred to as quantum coherence. This discovery led Popp to state that the capacity for evolution rests not on aggressive struggle and rivalry but on the capacity for communication and cooperation. In this sense the built-in capacity for species evolution is not based on the individual but rather living systems that are interlinked within a coherent whole: Living systems are thus neither the subjects alone, nor objects isolated, but both subjects and objects in a mutually communicating universe of meaning. . . . Just as the cells in an organism take on different tasks for the whole, different populations enfold information not only for themselves, but for all other organisms, expanding the consciousness of the whole, while at the same time becoming more and more aware of this collective consciousness.

Biophysicist Mae-Wan Ho describes how the living organism, including the human body, is coordinated throughout and is "coherent beyond our wildest dreams." It appears that every part of our body is "in communication with every other part through a dynamic, tunable, responsive, liquid crystalline medium that pervades the whole body, from organs and tissues to the interior of every cell."

What this tells us is that the medium of our bodies is a form of liquid crystal, an ideal transmitter of communication, resonance, and coherence. These relatively new developments in biophysics have discovered that all biological organisms are constituted of a liquid crystalline medium. Further, DNA is a liquid-crystal, lattice-type structure (which some refer to as a liquid crystal gel), whereby body cells are involved in a holographic instantaneous communication via the emitting of biophotons (a source based on light). This implies that all living biological organisms continuously emit radiations of light that form a field of coherence and communication. Moreover, biophysics has discovered that living organisms are permeated by quantum wave forms. [5]

Creating quantum technology

Another area of potential application is in quantum computing. The long-standing goal of the physicists and engineers working in this area is to manipulate data encoded in quantum bits (qubits) of information, such as the spin-up and spin-down states of an electron or of an atomic nucleus. Qubits can exist in both states at once, thus permitting the simultaneous exploration of all possible answers to the computation that they encode. In principle, this would give quantum computers the power to find the best solution far more quickly than today's computers can — but only if the qubits can maintain their coherence, without the noise of the surrounding environment, such as the jostling of neighboring atoms, destroying the synchrony of the waves. [6]

Quantum Entanglement

Measurements of physical properties such as position, momentum, spin, polarization, etc. performed on entangled particles are found to be appropriately correlated. For example, if a pair of particles is generated in such a way that their total spin is known to be zero, and one particle is found to have clockwise spin on a certain axis, then the spin of the other particle, measured on the same axis, will be found to be counterclockwise. Because of the nature of quantum measurement, however, this behavior gives rise to effects that can appear paradoxical: any measurement of a property of a particle can be seen as acting on that particle (e.g. by collapsing a number of superimposed states); and in the case of entangled particles, such action must be on the entangled system as a whole. It thus appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances. [4]

The Bridge

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. [1]

Accelerating charges

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field. In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion. The same thing happens on the atomic scale giving a dp impulse difference and a dx way difference between the different part of the not point like particles.

Relativistic effect

Another bridge between the classical and quantum mechanics in the realm of relativity is that the charge distribution is lowering in the reference frame of the accelerating charges linearly: $ds/dt = at$ (time coordinate), but in the reference frame of the current it is parabolic: $s = a/2\ t^2$ (geometric coordinate).

Heisenberg Uncertainty Relation

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 and proton are not point like particles, but has a real charge distribution.

Wave – Particle Duality

The accelerating electrons explains the wave – particle duality of the electrons and photons, since the elementary charges are distributed on delta x position with delta p impulse and creating a wave packet of the electron. The photon gives the electromagnetic particle of the mediating force of the electrons electromagnetic field with the same distribution of wavelengths.

Atomic model

The constantly accelerating electron in the Hydrogen atom is moving on the equipotential line of the proton and it's kinetic and potential energy will be constant. Its energy will change only when it is changing its way to another equipotential line with another value of potential energy or getting

free with enough kinetic energy. This means that the Rutherford-Bohr atomic model is right and only that changing acceleration of the electric charge causes radiation, not the steady acceleration. The steady acceleration of the charges only creates a centric parabolic steady electric field around the charge, the magnetic field. This gives the magnetic moment of the atoms, summing up the proton and electron magnetic moments caused by their circular motions and spins.

The Relativistic Bridge

Commonly accepted idea that the relativistic effect on the particle physics it is the fermions' spin - another unresolved problem in the classical concepts. If the electric charges can move only with accelerated motions in the self maintaining electromagnetic field, once upon a time they would reach the velocity of the electromagnetic field. The resolution of this problem is the spinning particle, constantly accelerating and not reaching the velocity of light because the acceleration is radial. One origin of the Quantum Physics is the Planck Distribution Law of the electromagnetic oscillators, giving equal intensity for 2 different wavelengths on any temperature. Any of these two wavelengths will give equal intensity diffraction patterns, building different asymmetric constructions, for example proton - electron structures (atoms), molecules, etc. Since the particles are centers of diffraction patterns they also have particle – wave duality as the electromagnetic waves have. [2]

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. The Electroweak Interaction shows that the Weak Interaction is basically electromagnetic in nature. The arrow of time shows the entropy grows by changing the temperature dependent diffraction patterns of the electromagnetic oscillators.

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.

Fermions and Bosons

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

Van Der Waals force

Named after the Dutch scientist Johannes Diderik van der Waals – who first proposed it in 1873 to explain the behaviour of gases – it is a very weak force that only becomes relevant when atoms and molecules are very close together. Fluctuations in the electronic cloud of an atom mean that it will have an instantaneous dipole moment. This can induce a dipole moment in a nearby atom, the result being an attractive dipole–dipole interaction.

Electromagnetic inertia and mass

Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

Relativistic change of mass

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

The frequency dependence of mass

Since $E = h\nu$ and $E = mc^2$, $m = h\nu / c^2$ that is the m depends only on the ν frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_o inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron – Proton mass rate

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force. [2]

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.

Gravity from the point of view of quantum physics

The Gravitational force

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 Mp=1840 Me. 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.

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.
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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 Higgs boson

By March 2013, the particle had been proven to behave, interact and decay in many of the expected ways predicted by the Standard Model, and was also tentatively confirmed to have + parity and zero spin, two fundamental criteria of a Higgs boson, making it also the first known scalar particle to be discovered in nature, although a number of other properties were not fully proven and some partial results do not yet precisely match those expected; in some cases data is also still awaited or being analyzed.

Since the Higgs boson is necessary to the W and Z bosons, the dipole change of the Weak interaction and the change in the magnetic effect caused gravitation must be conducted. The Wien law is also important to explain the Weak interaction, since it describes the T_{max} change and the diffraction patterns change. [2]

Higgs mechanism and Quantum Gravity

The magnetic induction creates a negative electric field, causing an electromagnetic inertia. Probably it is the mysterious Higgs field giving mass to the charged particles? We can think about the photon as an electron-positron pair, they have mass. The neutral particles are built from negative and positive charges, for example the neutron, decaying to proton and electron. The wave – particle duality makes sure that the particles are oscillating and creating magnetic induction as an inertial mass, explaining also the relativistic mass change. Higher frequency creates stronger magnetic induction, smaller frequency results lesser magnetic induction. It seems to me that the magnetic induction is the secret of the Higgs field.

In particle physics, the Higgs mechanism is a kind of mass generation mechanism, a process that gives mass to elementary particles. According to this theory, particles gain mass by interacting with the Higgs field that permeates all space. More precisely, the Higgs mechanism endows gauge bosons in a gauge theory with mass through absorption of Nambu–Goldstone bosons arising in spontaneous symmetry breaking.

The simplest implementation of the mechanism adds an extra Higgs field to the gauge theory. The spontaneous symmetry breaking of the underlying local symmetry triggers conversion of components of this Higgs field to Goldstone bosons which interact with (at least some of) the other fields in the theory, so as to produce mass terms for (at least some of) the gauge bosons. This mechanism may also leave behind elementary scalar (spin-0) particles, known as Higgs bosons.

In the Standard Model, the phrase "Higgs mechanism" refers specifically to the generation of masses for the $W^{\pm}$, and Z weak gauge bosons through electroweak symmetry breaking. The Large

Hadron Collider at CERN announced results consistent with the Higgs particle on July 4, 2012 but stressed that further testing is needed to confirm the Standard Model.

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 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]

Conclusions

Exists experimental evidence for quantum-coherent is used for more efficient light-harvesting in plant photosynthesis. Quantum entanglement exists in supramolecules determining the sense of smell and in the brain neurons microtubules due to quantum vibrations.

In the work presented here, we started to design and quantum mechanical investigations of the molecular logical devices which are useful for construction of nano medicine biorobots against the molecular diseases such a cancer tumors, and against the new kinds of synthesized microorganisms and nano guns. [7]

One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .

The accelerated charges self-maintaining potential shows the locality of the relativity, working on the quantum level also. [1]

The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. The Secret of Quantum Entanglement that the particles are diffraction patterns of the

electromagnetic waves and this way their quantum states every time is the result of the quantum state of the intermediate electromagnetic waves. [2]
These relatively new developments in biophysics have discovered that all biological organisms are constituted of a liquid crystalline medium. Further, DNA is a liquid-crystal, lattice-type structure (which some refer to as a liquid crystal gel), whereby body cells are involved in a holographic instantaneous communication via the emitting of biophotons (a source based on light). This implies that all living biological organisms continuously emit radiations of light that form a field of coherence and communication. Moreover, biophysics has discovered that living organisms are permeated by quantum wave forms. [5]
Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions also.

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