Camouflaged Contextual Posturing in the Laws of Nature: Hidden Riches for Novel Forms of Technology and Energy Generation

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Evidence will be presented from a wide spectrum of recent empirical and theoretical research to advance the thesis that the laws of nature, particularly in the astrophysical and microphysical arenas, are in some sense contextual, possibly dependent on both location and to a certain extent direction. The most compelling evidence to date to support this hypothesis will be brought forth – the surprising 2010 finding that the value of the fine structure constant appears slightly smaller than it was eons ago, if one looks in the northern sky direction, and incrementally higher if one scans the southern sky. This and the "chameleon" principle, which has been advanced to explain the anomalous acceleration of cosmic expansion, will also be shown to call into question one of the sacrosanct foundational tenets of general relativity, the Equivalence Principle. In the microphysical realm, it will be shown that the principles underlying quantum mechanics, especially superposition and counter-intuitive nature of entanglement, might naturally exhibit contextual qualities that have yet to be recognized and fully probed. In particular, it is argued that further progress in achieving mastery over the precise flexible manipulation of Bose-Einstein condensate (BEC) states could demonstrate that quantum contextuality might be an over-arching archetypal principle in nature, leading to new insight in regards to the interpretation of quantum mechanics as applied to all levels of nature Finally, it is demonstrated that this considerably fairly well hidden contextual aspect of natural laws, might be brought to bear to account for physical anomalies heretofore inexplicable using current paradigms, such as the claimed efficacy of homeopathic protocols. Moreover, acknowledgment of this novel principle of contextual posturing of natural laws even in the macroscopic regime might imply unplumbed prospects for development of new energy sources and forms of energy generation.

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1. Introduction

The aim of fundamental physics is to find laws governing the regularities exhibited universally by all physical systems, without exception, without qualification and without approximation. Since the time of Newton, the practice of the scientific method has been based on the presupposition that the universe is governed by strict causal laws that can be discovered and formalized by means of scientific observation and experiment. The laws of nature are statements of the uniformities and regularities in the wheel-work of nature, and are considered universal and invariable facts of the physical world. Accordingly, there are many axioms that have been canonized in connection with the assumed nature of physical laws, primarily based upon empirical observation at the macroscopic level of nature, chief among which are the following: They are *true*, at least within their regime of validity. They are *universal*, appearing to apply anywhere in the universe. They are *absolute*, as nothing in the universe appears to affect them. They are unchanged since first discovered (although they may have been shown to be approximations of more accurate laws), thus manifesting *stability* over time, and to a certain extent are *omnipotent*, as everything in the universe, according to observations, must comply with them.

However, in the last ten years evidence has been mounting that questions the continued accepted validity of these basic attributes of physical laws in certain particular regimes of application. It will be argued in this paper that, far from being independent of local conditions associated with space and time, in many respects the laws of nature might actually, at the primordial levels of reality – beyond space and time - be *contextually* postured. As a consequence, physically measurable properties of material bodies, and the customary yardsticks of nature, could ultimately be malleable and only be properly defined in terms of interactions with other bodies in their environment. The evidence which will be presented to support this contention will be taken primarily from the fields of astrophysics and quantum mechanics, and will provide a new means for explicating the many conundrums and mysteries facing science that have been discovered in these two disciplines in the last decade or so. In particular, by applying elements of quantum mechanics to a linear gravitational potential, it will be shown that the supposedly sacrosanct foundational tenet of general relativity – the Equivalence Principle, which describes the proportional relation between gravitational mass and inertial mass – may not be universally valid. Moreover, speculations are advanced that this hidden, essentially formerly unsuspected foundational contextual nature of physical laws has not been yet completely exploited, as it might provide explanation for many phenomenological anomalies presently beyond the pale of current accepted paradigms. With this new insight, the present inexplicable but documented evidence of the efficacy of homeopathic protocols and low energy nuclear reactions (as represented in the so-called process of "cold fusion"),

for instance, might be made more tractable and be rendered less controversial.

2. Contextuality as Basis for Quantum Behavior

It is universally accepted that the nature of the foundational tenets of quantum physics relate to contextual features of the systems that are investigated in connection with the properties measured in those systems. Contrary to the situation in classical mechanics, within quantum mechanics one can have maximal knowledge of a composite physical system and still not be able to assign a definite state to its constituent elements without reference to their relation to one another. As a result, unlike classical mechanics, these theories require the results of measurements on a quantum system to be dependent upon the act and specific properties (the context) of the measurement process itself. Accompanying this situation, one must grapple with the inescapable counterintuitive notions of quantum superposition and entanglement. Efforts to demystify this theory and reconcile it with the laws of classical physics have led to the theories of hidden local variables – the hypothetical parameters of a quantum system that govern the seemingly random outcomes of quantum measurements. These so-called "hidden variables" theories require quantum mechanics to be non-contextual. Yet, as more evidence surfaces in connection with the practice and philosophy of quantum physics, it has become less-likely that such quasi-classical hidden variable theories eventually will rule the day, rendering the supposed contextual nature of quantum physics central to any future theory able to describe the laws of nature, and the forces associated with them, in a unified formalized manner. In this connection it has recently been demonstrated [1,2] that the results of an experiment on a system of trapped ions shows unequivocally that quantum mechanics conflicts with non-contextuality regardless of the quantum state of the system. This means that the result of one measurement depends on which other measurements are performed simultaneously. Moreover, here the simultaneous measurements must be compatible and do not disturb each other. This is a significant advance, coming on the heels of recent tests also upholding quantum contextuality, performed with photons [3] and neutrons [4] in very special quantum states.

The celebrated Bell's inequality [5], the violation of which by quantum systems has been used as a benchmark to challenge or refute hidden variable theories, requires the preparation of a very specific quantum state called the entangled state. But in general, other types of quantum states do not violate this inequality. A definitive test of non-contextuality would involve demonstration of a Bell-like inequality for *any* quantum state, not just the entangled state. Such a test involves many more sequential operations and measurements on the quantum states than Bell-inequality tests. In addition, the measurements themselves must be compatible, meaning if they are done sequentially or simultaneously, should not be affected by the order in which they are performed.

In their experiment, Kirchmair and colleagues used a pair of trapped ions for which almost any spin state could be prepared on demand. Following the spin-state preparation step, they made a sequence of compatible measurements on the spin states to test whether a Bell-like inequality was obeyed or violated. Each sequence involved included measurements of various spin components. Remarkably, for all ten quantum states tested, they observed a strong violation of the inequality – a clear demonstration of the contextual nature of quantum mechanics. Thus, for the first time in an experiment, it was shown that the empirically observed phenomena cannot be described by non-contextual models with hidden variables.

These tests where the Bell inequality is violated, showing quantum mechanics to be in conflict with non-contextuality, usually have involved compatible measurements on microscopic quantum systems such as ion spins or photon polarizations, and were for a long time thought inapplicable to systems at the macroscopic level of nature. However, recently it was demonstrated that this supposed associated non-contextual property of classical physics called "macroscopic realism" has also been seriously called into question. Operating from a 1985 paper [6] which introduced what is called Bell's inequality in time, to be applied to the flux measurement on a superconducting ring, Agustin Palacios-Laloy and colleagues [7] reported on an experimental realisation of the Leggett-Garg test. Using a superconducting circuit similar to that proposed originally, which supports a quantum two-level system (TLS), they employed a so-called transmon, which is a combination of a Cooper-pair transistor and a high-quality micrometer size superconducting oscillator operating at 5 GHz. Making use of the transmon's long coherence times, these researchers continuously drove transitions of the TLS between its ground and excited state with a microwave signal. Macroscopic realism requires the system to be in one of its two states at all times. However, performing weak measurements on the system at various times, Palacios-Laloy and colleagues observed a distinct violation of the Leggett-Garg inequality, leading to the inescapable conclusion that the behavior of even a 'macroscopic object' clearly follows the laws of quantum mechanics.

3. Photosynthesis as Quantum-Assisted Process

It has also been recognized that entanglement is a natural feature of coherent evolution, and recently there have been attempts to extend the realms in which it can be shown to exist robustly and rigorously, particularly in natural systems - those outside of one's manufactured in laboratory conditions. Signatures of entanglement, a characteristically quantum feature, have been demonstrated in thermal states of bulk systems at low temperatures and between parties at macroscopic length scales. The possibility of entanglement even in noisy non-equilibrium systems at high temperatures intimates the question of whether entanglement can be observed in the complex chemical and biological processes necessary for life. In this regard, recently there has been strong evidence to suggest the affirmative answer to this question by the determination of timescales and temperatures for which coherent quantum processes are observable in a protein structure that is central to photosynthesis by green anoxygenic bacteria.

During the initial stages of photosynthesis, light is captured by pigment protein antennas known as Light Harvesting Complexes (LHC), and the excitation energy is then transferred through these antennas to reaction centers where photosynthetic chemical reactions are initiated with almost 100% efficiency.

Speed is the key – the transfer of solar energy takes place almost instantaneously so little energy is wasted as heat. How photosynthesis achieves this near instantaneous energy transfer is a long-standing mystery that may have been finally solved. Recent ultrafast spectroscopic studies have revealed the presence of coherence at femtosecond timescales in biological structures, specifically in LHC [8]. These studies demonstrate that, in moderately strongly coupled non-equilibrium systems, quantum features can be observed even in the presence of a poorly controlled decohering environment. Average interchromophore separations on the scale of ~15 Angstroms are fairly common, leading to considerable dipole coupling of these molecules and coherent interactions at observable timescales. The quantum coherence manifests itself in characteristic directly observable quantum beating signals among the excitons within the bacteriochlorophyll complex at 77 degrees K. The remarkable long-lived wavelike quantum beating coherence plays an important role in energy transfer process during photosynthesis. This wavelike characteristic can explain the extreme efficiency of the energy transfer because it enables the system to simultaneously sample all the energy pathways and choose the most efficient one. This finding contradicts the classical description of the photosynthetic energy transfer as one in which excitation energy hops from light capturing pigment molecules to reaction center molecules step-by-step down the molecular energy ladder.

Following on the heels of this discovery, similar recent studies were done on two kinds of light harvesting protein found in cryptophyte algae, taking advantage of the fact that the main pigment in these proteins, known as bilin, can be tuned to absorb light across a wide range of frequencies [9]. The proteins were first exposed to a pair of short duration laser pulses exciting the constituent pigment molecules, thus populating the different electronic levels of the system and creating electronic coherences (wavelike behavior) between the different levels. The evolution of the excited state was then measured by following the spectral response of the 'photon echo' – the emitted light that was induced by a delayed third pulse. By plotting the emission wavelength as a function of the excitation wavelength, a two-dimensional spectrum was then obtained before stimulating emission from these excited states by sending in a third pulse shortly afterwards. The team observed pronounced oscillations in the diagonal peaks and off-diagonal cross-peaks of the spectra showing emission frequencies that did not match the excitation frequency - a definite signature of the existence of a superposition of different states. The researchers also found that the oscillations of this coherent superposition lasted for over 400 femtoseconds, much longer than the 100 fs timescale over which they thought interference from the surrounding protein and water molecules would decohere the delicate quantum superposition state. This is remarkable considering that bilin molecules interact more weakly with one another than do other photosynthetic pigments. Moreover, the coherence occurred between pigments that are distant from from each other, and so weakly coupled. Above all, in contrast to the earlier work done by the Engel team, this latest work was carried out at room temperature, suggesting that quantum coherence really does play a role in photosynthesis.

The framework for quantification of entanglement in LHCs is an essential step in the precise characterization of quantum resources in organic structures, and is of particular relevance to the enterprise of constructing quantum devices from such structures. In fact, densely packed molecular aggregates such as LHCs have potential for constructing naturally robust quantum devices. For example, ultrafast quantum state transfer facilitated by excitation migration along engineered or self-assembled chromospheric arrays could be a possible realization of the 'quantum wires' that are much desired in quantum technology. Entanglement between subunits in such arrays is essential for high fidelity quantum transport, and as the above studies show, such quantum coherence is possible in molecular aggregate structures even at room temperature. Integration of such molecular aggregates with standard solid state devices opens up the possibility of engineering controllable quantum-coherent soft matter structures that can be used to distribute quantum states or entanglement.

These findings lead us to consider the foundational significance of entanglement in many other types of areas of scientific investigation: it represents a uniquely quantum form of strong correlation between physical systems. The identification of entanglement between spatially distinct components of a biological system under natural functioning conditions further expands the field of physical systems for which non-trivial and uniquely quantum signatures become manifest. This is a significant advance implying that this factor of quantum contextuality, might actually be a heretofore unsuspected over-arching principle that could lead to new insight in regards to the actual structure of quantum mechanics itself and its interpretation as applied to *all* levels of nature. Perhaps the seeds for this eventual revolution have already been sown with recent work to be described next.

4. Entanglement: The Contextual Posturing of Nature?

In the arena of theoretical investigations into the foundations of quantum physics, a possibly seminal paper by one of the chief architects of quantum information theory, Andrew Steane, has emerged [10]. Underscoring the supreme importance of contextual factors, it questions the presupposition of the reliance on the formalistic idea of a quantum "state" of a system, underpinned by Schrodinger's equation describing the notion of gradual unitary evolution of quantum state through time, and raises to prominence the fundamental role in physics of interactions and correlations, as opposed to internal properties of systems. Rather, 'properties' should primarily be viewed as a useful way to summarize collections between entities. Steane elevates to primary status the symmetry principle called the principle of 'contextuality' – the assertion that physical entities cannot possess physical properties in and of themselves. Interactions and correlations between entities are more fundamental, and properties such as mass, velocity, etc. arise by a type of symmetry breaking. Basic theories of kinematics and dynamics must respect this symmetry and this may be regarded as a partial explanation for some of the basic features of quantum mechanics. Correlations can be considered as invariants of the associated transformation. Steane claims all alternate formulations of quantum mechanics are lacking since they do not satisfactorily treat the one ingre-

dient to experimentally observed behavior. This is the everyday observation that the universe evolves in a non-unitary way. Quantum theory correctly predicts the type and degree of correlation to be expected between systems, but physical systems express these correlations by randomly adopting physical configurations drawn from an appropriate set of alternatives. Moreover, because interactions and correlations are more fundamental than the entities interacting and correlated, physical entities have to be considered in groups of at least *three* in order to allow statements about what transpires; two to have an interaction, and a third to be influenced by the result. Operating mainly from a modified version of Cramer's transactional interpretation of quantum mechanics [11,12,13], Steane presents just such a toy Gedankan experiment that features the central role of the above-mentioned novel *triality* principle of interaction. Also, central to Steane's approach is the postulate that, even though the equations of quantum mechanics are time-reversible, there are in nature processes that are not reversed on any time scale that we are able to assign meaning, such as lifetime of galaxies, the proton decay time, etc. This allows him to define quantum unitary evolution as 'atemporal'. For a process to be non-reversed here, it is sufficient if the equations of motion are time-reversible but the motion is such that it never gets reversed in practice. According to these precepts, it is possible to have objective physical events if and only if some processes are non-reversed. Consequently, operating from a position that emphasizes a three-stage interaction process, the tension between reversibility and irreversibility is consequently the same as the tension between contextuality and objectivity. One remarkable feature of the Steane interpretational framework is that, unlike any previous formulations of quantum mechanics, by positing contextual interaction factors as central to its structure, it allows the formerly counter-intuitive notions of quantum superposition and entanglement to enter into the system in a purely natural manner and be ascertained from a fresh standpoint. Moreover, this unique contextual approach to system interaction involving the 'atemporal' nature of quantum evolution, sharpens our understanding of the role played by the wave function, and conflates the often noted paradoxical conceptual tension between quantum unitary evolution and the state vector reduction or so-called "collapse" of the wave function in the measurement process [14].

However, as with all theoretical frameworks, it seems likely that there may eventually be limits discovered to quantum theory and the validity of its principle of superposition as there has been for all other candidates for a fundamental theory to date. However, the remarkable fact about the history of this most successful of all physical theories is that, despite the limited range over which it has been experimentally verified, there are no alternative theories that are consistent with these experiments, consistent with the rest of modern physics, but which differ their predictions in domains not tested. This fact alone leads one to conjecture that the apparent contextual principles founding the theoretical framework of quantum physics might be equally important in not only eventually providing an able successor to this edifice, but could serve as an apt metaphor for future theoretical and empirical investigations into other areas of science. As we shall see, there have been indications of just such developments, as yet unsuspected, revealing phenomena exhibiting the primary hallmark of contextuality.

5. The Chameleon Hypothesis, Astrophysical Anomalies and Technological Ramifications

As years have passed, many researchers have wondered whether the fundamental constants of nature might have been different when the universe was younger. If so, evidence would be out there in the cosmos where distant objects can be seen exactly as they were in the past. About ten years ago, exactly this kind of evidence has emerged from studies of light absorption spectra from quasars on distant gas clouds, with the Keck telescope in Hawaii [15]. The data suggested that the value of the fine structure constant (alpha) was very slightly *smaller* when the quasar light was emitted 12 billion years ago than it appears in Earth laboratories today. At the time when this finding was announced it was naturally quite controversial, since as stated in the introduction the laws of physics, and associated constants, are assumed to be absolute, universal, and stable. However, in the decade that has passed since this discovery, no significant evidence has emerged to contradict this finding. Moreover, much more recently [16], the same research team announced an even more startling discovery. Whereas the Keck telescope obtained its data by scanning the northern hemisphere, analysis of new data obtained from the Very Large Telescope (VLT) in Chile which looks out into the southern sky, found that alpha was incrementally *larger* eons ago. Just the very opposite that was discovered from the Keck telescope earlier. If this new finding is supported, it will mean that not only does alpha vary in time, but also in different spatial locations in the universe. In addition, the team's analysis of around 300 measurements of alpha in light coming from various points in the sky suggests the variation is not random but structured, like a bar magnet. The universe appears to have a large alpha on one side and a smaller one on the other. If correct, this result showing the change in alpha has an orientation, stands in direct conflict with Einstein's special theory of relativity, which prohibits a 'preferred direction' or axis across the cosmos. Also, qualitatively these findings suggest a violation of the Einstein Equivalence Principle (EP), which presupposes the proportional relationship between inertial mass and gravitational mass, and could infer a very large or infinite universe, within which our 'local' Hubble volume represents a tiny fraction, with correspondingly small variations in the physical constants. As we shall see later recent developments in quantum physics also apparently may imply a further quantitative assault on the universality of the EP.

A major development in astrophysics research is the supposed existence of a dark matter or dark energy that has been introduced to explain the accelerated expansion of the cosmos. But while this entity apparently produces a repulsive force counter to gravity, it has never been detected in the lab and seemingly does not interact with light or matter on Earth or in deep space. While the results so far are striking, techniques used to probe dark energy have been insufficient in separating different theoretical models for this mysterious entity. After many unsuccessful attempts to explain dark energy by other means, one of the most promising models has been bought forth

to account for this hypothetical form of energy. Termed the "chameleon" hypothesis, its originators, Justin Khoury and Amanda Weltman, in 2003 posited a new class of particles able to change its mass on its own, depending entirely upon the energy density in their surroundings [17]. Due to the extreme low energy density in the cosmos, the range of the chameleon force would be large enough to drive the expansion of the universe, but on Earth its mass would be quite large, implying a very small range in the area of a millimeter. In that scenario, Khoury & Weltman argued its effects could indeed remain veiled on Earth. This recently enabled other teams to illustrate for the first time how dark energy models could be probed in the laboratory [18,19]. The Chou group focused on the possibility that the photon in a strong enough magnetic field could could occasionally decay into a chameleon particle, which could in turn change back into a photon. The GammeV experiment at Fermilab is designed to measure just such possible photon oscillations. It involves bouncing a laser beam around a cavity with glass windows for about 5 hours, and then switching it off. If the chameleon theory holds, some photons will oscillate into chameleon particles that will bounce off the windows rather than pass through. Some of these will oscillate back into photons and escape, producing a visible afterglow. Although the GammeV experiment has so far produced null results, other types of lab experiments have been inaugurated to search for chameleons. For instance, Brax and company claimed it can be shown that the chameleon pressure between two parallel plates in vacuum at a separation of a few tens of micrometers is of the same order as the Casimir attraction under the same conditions, reaching values within the detection sensitivity of long-range Casimir experiments, with separations larger than 1 micrometer. Yet such long-range Casimir tests suffer from the drawback that large plate surfaces are needed to reach the force detection limit. The electrostatic potential of a large surface, however, is generally nonuniform giving rise to background forces that easily overcome Casimir attraction. In the reference above, the Brax group proposed a novel approach that might alleviate such problems. The idea involves measuring the total force between two parallel plates as a function of the density of a neutral gas placed into the cavity. As the gas density increases, chameleon mass would also increase, giving rise to a screening effect of the chameleon interaction. If all other significant forces between the two plates (Casimir and electrostatic) do not depend on the density of the gas in the gap, a direct comparison of the results obtained at low densities (strong chameleon force) with those obtained at high densities (weak chameleon force) should permit the detection of chameleon particles or to rule out their existence. Furthermore, positive results in space tests for chameleons, could lead to EP violations, variations in alpha, fifth force effects and unexpected scalar field interactions between known particles [20,21]. The chameleon mechanism, by which a matter coupling and a nonlinear self interaction conspire to give a field an environment-dependent effective mass, might not only resolve these issues while providing an apt candidate for dark energy, but furnish further evidence for the underlying hidden fundamental contextual nature of physical laws.

For instance, could the empirical evidence exhibiting the dynamics of chameleon energy-mass, as manifested in an astrophysical or laboratory context, be presenting us with a clue for a more profound understanding of the origin or the actual dynamical engine responsible for the existence of mass and what is perceived as the apparent permanence of matter itself on the macroscopic level of nature. If so, might these notions be pointing us to consider the possibility of being able to achieve actual technological applications mimicking chameleon mechanics - to energetically apply certain field effects in appropriate engineering protocols to enable the alteration of the mass of an object.

There may be a precedent for such phenomena in the largely ignored work of John Hutchison by mainstream physics. Primarily anecdotal but highly documented evidence by respected technicians have chronicled the manifestation of sporadic but spectacular events in matter, going under the general name of "Hutchison effect" [22]. By application of specific electromagnetic and electrostatic field protocols, levitation of heavy objects and catastrophic fracturing of the molecular structure of certain metallic substances were just some of the bizarre effects observed and documented. Operating from a different format, if we take this new concept of chameleon environment-dependent mass seriously and are able to develop a viable theoretical framework for its existence, what is considered to some as purely the province of science fiction could become a reality. Already there is recent possible evidence that mass in a quantum context might not behave the same as its macroscopic classical counterpart. We turn to these developments next.

6. Evidence for Cracks in the Equivalence Principle?

The Equivalence Principle (EP) is indeed a cornerstone in the foundations of Einstein's theory of general relativity. The associated assumption of the proportionality of inertial and gravitational mass implies that in a linear gravitational potential all bodies experience the same acceleration and fall at the same rate. In a landmark paper, Kajari and colleagues investigated theoretically the question of how the inertial and gravitational mass enter in non-relativistic quantum mechanics [23]. They showed that in total agreement with classical mechanics, the dynamics of any quantum mechanical wave packet in a linear gravitational potential involves the *ratio* of the two masses. However, depending on the specific preparation of the initial state, inertial and gravitational mass may appear in a quantitatively more complicated way in the time evolution of a physical state. They found that the spatial modulation of the energy eigenfunctions depends on the third root of the *product* of the two masses. Moreover, the discrete energy spectrum of a particle constrained in its motion by a linear gravitational potential and an infinitely steep wall depends on these two masses with different fractional powers. They claimed that this feature might open up a new avenue for experimental tests of the EP. On the heels of these findings by the Kajari group, German researchers from the Max Planck Institute of Quantum Optics have proposed a test to drop a piece of apparatus, in which they generated a weightless Bose-Einstein condensate (BEC), to the bottom of a 146 meter drop tower. The particles in a BEC lose their individuality, behave coherently and can be considered to

be a 'super-particle' [24]. A wave packet of matter forms in which the atoms are delocalized, the BEC is split into two parts and moves in the gravitational field along different paths in space-time. Gravitation behaves like an optical medium, whose refractive index refracts the quantum waves. When the two parts unite, there is interference which depends on how differently the matter waves expand. These differences can correspondingly be measured in an atom interferometer. The researchers plan to use such an ultra-cold quantum gas at zero gravity to construct an extremely sensitive measuring device for the Earth's gravitational field, as well as to provide accurate tests for the EP. Many standard accepted universal principles in mainstream science such as EP may have to undergo re-evaluation under the increasing evidence for the overwhelming effects of contextuality. However, far from the arena of standard practices in science, many so-called fringe subjects and phenomena may also get an unexpected welcome boost or thrust to respectability from placing an emphasis on the novel principle of contextuality in nature. One such prominent case is illustrated next.

7. Efficacy of Homeopathic Protocols

The practice of homeopathy as a medical modality for alleviating pain and mitigating illness, has enjoyed a long history of success primarily from continued anecdotal evidence of efficacy in the administration of such protocols. These involve a dilution of the intended curative agent in water or ethynol below the level of Avogadro's number effectively removing any physical trace of the original substance. The liquid is then shaken vigorously or succussed before being ingested by the patient. However, due to the absence of any chemical form of the original substance, it has been argued that it is impossible for remedies delivered in this manner to work. However in a recent paper, [25] provides an interdisciplinary base of information on the structure of liquid water. Roy *et al.* presents an argument which essentially nullifies this claim, stressing it is water *structure* not *composition* which could have this effect. Roy underscores the confusion in the field as due to the use of the same term to mean different things. Chemists use "structure" to describe molecules or building blocks, whereas the materials scientist use this word to describe the 3-D architecture of the material – the size and shape of the walls and the room and how the blocks are arranged in it. Building on this key distinction, Roy emphasizes the undue emphasis chemistry has placed on water's molecular composition, causing them to hold the naïve view that all liquids are more or less homogeneous in structure down to the unit cell, and exhibit characteristics of the random network model. This has resulted in their relative ignorance of the equally significant materials research findings that point to the structure of water as being nano-heterogeneous. Roy discusses other influences on the study of water structure, pertinent to the issue of homeopathy, which might also have been overlooked due to the primary chemical approach to water behavior. These are the role of epitaxy, the colloidal state, effects of pressure generation through succession, and the influences of magnetic and electric fields and human "intentions".

Epitaxy is the transmission of structural information from the surface of one material (usually a crystalline solid) to another (usually a liquid), without transfer of matter composition. The absence of compositional dissolution in this process underscores the significance of "contextual" factors underlying such dynamics. Citing these particular factors possibly being prominent in dilution protocols, Roy thus renders groundless the assertion by the biochemical and medical communities that it is only the presence in solution of finite concentrations of the active agent that can affect a liquid by noting structure in homeopathic preparations can be transferred by epitaxy. Due to the potential structural heterogeneity within all covalent liquids, water can therefore possibly be influenced by the structure of the solids with which it is in contact, without involving their compositional dissolution at all.

Roy underscores the possible "imprinting" process on water may also be caused by the dynamics of succussion as rapid pressure changes due to shaking may introduce stable nano-colloid bubbles. These nano-clusters of water have been proven without a doubt to exist and persist in water. Clusters around certain foreign ions at great dilutions have been shown to grow to the micrometer range. It appears that there is an equilibrium in the solution between clusters and aggregates of clusters, which is dynamic and dependent on various factors such as concentration, solution history, temperature, nanobubble and pressure effects. This complex heterogeneity makes the equilibrium distribution more susceptible to change by the total homeopathic preparation process, including succussion.

The connection of the imprinting, primarily via succussion and possible epitaxy, of the different specific homeopathic remedies on the structure of water eliminates the primitive criticism of homeopathy being untenable due to the absence of any remnant of the molecules. As Roy underscores, structures change properties vastly more easily and dramatically than chemistry changes them. These facts provide a theoretical plausibility for the data of countless researchers in the homeopathic field, who have reached more or less similar conclusions by other routes.

8. Manipulation of Light: Classical Contextuality Revealed?

Discoveries during the first decade of the millennium have brought forth surprises and revelations in regards to our previous limited understanding of the properties associated with even phenomena normally relegated to the classical macroscopic realm of mainstream physics. In particular, some of these innovations relate to new means to technologically control the propagation attributes of light: refraction, diffraction, dispersion and especially speed of transmission of a signal. The most remarkable of these advances pertain to the last of these characteristics – the precise control of speed of a signal, particularly the recent achievement of slowing light to a crawl and ultimately 'storing' or stopping the progress of light for a few seconds [26]. The unique phenomena that has made all these feats possible, is an entirely new state of matter first produced and observed in 1995. This state was originally conceived by Albert Einstein and Satyendra Bose in 1924. According to their theory, atoms crowded close enough in ultra-low temperatures, would expand their De Broglie wavelengths to the size of the

inter-atomic distance. In this regime the atoms lose their identity as individual particles, and being in the same quantum state, act like a single super atom with coherent wave characteristics very similar to those of photons in a laser. This so-called Bose-Einstein condensate (BEC) has been used in an unprecedented manner to produce an enormously rapidly varying index of refraction of laser light, subsequently creating a huge reduction in the speed of light. Hau and her team achieved their success by utilizing a special system consisting of a sodium atom BEC at about 50 nanokelvins bathed in two beams of laser light. The first beam continuously shined through the width of the BEC cylinder cloud. This controls the speed of a second pulsed laser beam, subsequently shot along the length of the cloud. The first laser sets up a quantum interference between the two beams of laser light, creating a huge index of refraction, an accompanying phenomenon called electromagnetically induced transparency in the cloud, and a slowing of the group velocity of light by a factor of 20 million.

Despite these tremendous advances, such phenomena produced by BEC states are still primarily considered a laboratory curiosity, and practical technological application of these exotic states still is apparently a long way off. Nevertheless finding new ways to control light might pave the way for protocols that use light in this manner to store and transmit information much more efficiently and at low power. Moreover, there are the as yet unexploited profound theoretical ramifications surrounding such developments pertaining to the theme of this paper, associated with further demonstrations of the contextual aspect of nature in the quantum arena. The mere fact that in the BEC state atoms mimic the coherent nature of photons in a laser should provide an important clue to certify this connection.

Also, this researcher speculates that the newly discovered properties of BEC might possibly lead to better understanding of the origin of the universe itself, if it becomes possible to construct a refracting telescope with a non-matter plasma trapped BEC serving as a lens. Given the enormous refractive indexes that can be produced using BECs, which are of several magnitudes greater than that of the opthalmology-grade glass currently used as optical lenses in telescope construction, the smaller or compact the telescope can be made, compared to one made with lenses with a lower refractive index – even if both of them are rated with the same powers of magnification. However, at present, the near absolute zero requirement for temperatures of BEC renders impractical the construction of such a telescope with magnification ability comparable to the Keck telescope in Hawaii, since the cooling system to maintain the structural integrity of a BEC lens would have to be the size of St. Paul's Cathedral. Nevertheless, this proposal is presented in hopes that physicists will be able to surmount these problems in the future to produce a viable prototype to inaugurate an era hallmarked by the unprecedented probing of the mysteries of the universe via the first historical application of what could be termed "quantum sight".

More remarkable recent revelations challenging even the assumed characteristics of the BEC have emerged from the unprecedented empirical demonstration of something heretofore thought impossible – the formation of a *non-atomic* Bose-Einstein distribution from the photonic energy of blackbody radiation [27]. Yet, radiation in thermal equilibrium with cavity walls does not exhibit the phase transition commonly associated with the chemical potential of conserved atomic matter in standard BECs. In such systems, photons have a vanishing chemical potential, meaning that their number is not conserved when the temperature of the photon gas is varied. To build the customary BEC, atoms must usually collide with each other, to even out their temperature. But photons, even those with a slight mass, interact too weakly to do this. However, in this benchmark experiment, by confining light within the narrow slice of space between two barely separated mirrors, and filling the slab-like cavity with a red liquid dye material, the Klaers group achieved thermal equilibration of light as a gas of conserved particles, rather than ordinary blackbody radiation. The added dye molecules absorbed and re-emitted the photons from a laser fired at the cavity, assisting them in reaching thermal equilibrium. By pumping more photons into the cavity, a critical point is reached where extra photons, prevented from entering the thermal equilibrium, undergo a quantum transition, dropping into the same low energy state and forming a BEC. When the low energy photons at the center of the cavity reached a density of about a trillion photons per cubic centimeter, they began to act as a single photon, shifting in appearance from a blurry glow to a bright point. Moreover, this feat was achieved without the use of cumbersome standard laser- and evaporative-cooling cryogenic techniques that are normally a prerequisite for formation of the BEC. The Klaers work was carried out at room temperature. Such new understanding associated with the reality of photon BECs and the possible non-requirement of delicate hard to maintain cryogenic states for their existence, will undoubtedly be instrumental in transforming the current view of BECs as mere lab curiosities to perception of their possible full-fledged status as operating components in energy-efficient mechanical, optical and electrical systems (see the following section). Accordingly, this new development sheds fresh light on the efficacy in developing various future mass-produced technological applications using BECs, such as the proposal above regarding the 'quantum telescope', plus a possible alternative way of generating laser beams, as well as the long-sought after quantum computer. Along these lines, Martin Weitz of the Klaers group has commented that this work could help further shrink electronic devices. Ultraviolet light (UV) has a short wavelength, making it an ideal tool to burn small patterns into computer chips. But UV lasers are difficult to make. If UV photons can be cooled in the same way that the optical photons in this study were, a photon BEC could serve as a new high-energy UV photon source, Weitz says. A personage no less august than Wolfgang Ketterle at MIT in Cambridge, who won a share of the 2001 Nobel Prize in physics for leading the research group that first generated a BEC with atoms, describes the work as a "spectacular work of physics that removes one more distinction between atoms and light".

9. Control of Superfluid Flow in a BEC: An 'Atomtronic' Circuit

An even more extraordinary practical technological advance

in the manipulation of a BEC has emerged with even more recent research that has implications which strongly support and corroborate the theme of this paper. In spring 2011 researchers have established, for the first time, fairly precise control - in terms of being able to start and stop - the rotation of the superfluid state in a toroidal sodium Bose-Einstein condensate medium [28]. The frictionless rotating quantum matter wave simulates the role of electrons in superconductivity, and thus opens the door for the possible utilization of BECs as essential circuit elements for future means to afford the efficient transformation and transmission of energy. This new methodology, which has been termed 'atomtronics' by scientists, could also set the stage for a new generation of ultracold-gas-based precision sensors. In this regard, scientists have already produced electronic-based superconducting quantum interference devices (SQUIDS) employing superconducting electrons in a loop to make highly sensitive measurements of magnetic fields. In atomic Bose-Einstein condensates, researchers have previously created Josephson junctions – a thin barrier separating two superfluid regions - in a single atomic trap. One of the aims in creating matter-wave analogs of electronic circuits is towards the eventual development of an ultracold-gas version of a SQUID which could detect rotation. The present work represents an important step in this direction since it involves the implementation of an atom circuit, containing a superfluid ring of current and a tunable "weak link" barrier.

In the new experiment, the research team created a toroidal condensate by cooling sodium atoms almost to the point of quantum degeneracy in a magnetic trap which were then transferred to an optical dipole trap created by the intersection of a red-detuned (1030 nm) "sheet" and "ring' laser beams. The horizontal sheet beam has a vertical (horizontal) half-width of 9 micrometers (400 micrometers), and provides vertical confinement for the condensate. The vertical ring beam is Laguerre-Gaussian and confines the condensate to its 20 micrometer radial intensity peak, generating a toroidal potential minimum. With the atoms in this optical trap, the beam intensities are then ramped down to force evaporative cooling. Circulation of the initially non-rotating condensate is attained by transferring quantized angular momentum from optical fields during a Raman process. The angular momentum change of the condensate is determined by the spatial mode of the Raman beams. Circulation is detected by releasing the condensate from the trap and imaging the density distribution after several milliseconds time-of-flight. If the condensate is not rotating, the central hole closes after a short time. However, when a rotating condensate is released, the angular velocity of the flow prevents complete closure. It is the persistence of the central hole after sufficiently long time-of-flight which is the signature of circulation in the ring. Persistent flow – occurring for a record high 40 seconds in this experiment – is a hallmark of superfluidity. The method used to start and stop the flow was via a circuit element – a so-called weak tunable link. This repulsive barrier is created with a blue-detuned (532 nm) laser beam focused to an elliptical spot. The barrier depletes the local density of the condensate increasing the azimuthal velocity of the atoms, thus constituting a tunable "weak link" that can turn off the current around the loop. Superflow stops abruptly when the barrier strength is sufficiently high. When the condensate velocity reaches a critical value, the atoms encounter resistance to flow (viscosity) and the circulation stops. The researchers described the system as "the first realization of a nontrivial closed atom circuit, demonstrating precise control in both inducing and arresting superfluid flow"[28], and is a significant step in setting the stage for production of an atomic SQUID analog.

As well as the above being landmark achievements in themselves, making photons behave thermodynamically as atoms, even to the point of Bose-Einstein condensation, as well as establishing control of circulation of a toroidal matter-wave, illustrates a broader theme in physics complementing the major theme of this paper. As noted above, atomic gases have been made to behave as laser light and now, conversely, photons have been shown to mimic atomic structure, and most amazingly atoms (bosons) may now be able to play the role of electrons (fermions) in a tunable circuit. The discernible trend is that in terms of the underlying contextual quantum engine possibly underpinning physical reality, everything is becoming, or at the very least is capable of masquerading as everything else. Beyond space and time we may find that physics could be the *art* of the interchangeable. But in the proliferation of these startling masquerades, physical science is also taking on more than ever the aspect of *creative art*, in a medium that, with the advances of modern technology, is proving far less constraining than it once seemed.

10. Conclusion

As the examples from astrophysics and quantum physics presented in this paper amply reveal, the future of scientific advancement is at a precipice or threshold in confronting the implications provided by the evidence of the increasing role contextuality is playing in gradually reshaping the foundations of natural law. To some this is not good news – especially those of the 'old guard' who will undoubtedly be facing the psychological effects of cognitive dissonance. As an example, the discipline of cosmology may have to face the greatest misapprehension it has harbored for over 100 years – the unquestioned assumption that physical laws are exactly the same in all parts of the cosmos, as they are in our little corner. However, it is certain the advantages of embracing new paradigms will greatly outweigh the disadvantages. One upside to recognition by the scientific establishment of the heretofore hidden archetypal role of the contextual paradigm, is the exciting possibility of revealing new exotic energy sources and modes of energy generation. Along these lines, the documented evidence of energy production via low energy electrochemical nuclear reactions, which was discounted out of hand when first discovered in 1989, may get a fresh breath of life. Indeed, if it is revealed that the reason these methods were not originally reliable in producing consistent results was actually due to unsuspected quantum contextual factors related to the nature of primordial reality – beyond space and time – the new knowledge provided by the contextual paradigm, possibly with new heretofore unfathomed designs incorporating ultra-cold atomic and/or photonic BECs, can be brought to bear to solve these

problems. Already, the spectacular recent finding that photosynthesis may be quantum-assisted may lead us to possible technological means to mimic nature to create artificial versions of light-harvesting that would help us to effectively tap into the sun directly as never before for a clean, efficient, sustainable and carbon-neutral source of energy. The implications of this knowledge base for developing new means of propulsion alone would be astounding. Those devices formerly thought to be the province of science fiction may become reality as science uses the possible structure and operational principles of chameleon particles/dark energy in developing technology that would be capable of "tuning" masses at the macroscopic level, effectively rendering rocket technology for space travel obsolete.

11. Prospects

As this paper goes to press, several new studies have come to light that shows the paradigm underlying quantum superposition as continuing to take a cross-disciplinary role across the boundaries of science. One of many such primary avenues of research are the recent findings that posits quantum coherence may be the key to understanding not only the keen sense of smell possessed by many animal species [29], but also the dynamics behind a hidden quantum compass which may be central for the ability of certain bird species to navigate [30,31,32]. As time passes, discoveries continue to emerge to reveal that the contextual posturing of nature might be a major pillar for formulating any future viable unified physical theory. Moreover, on a more archetypal panoramic scale, our ideas about contextuality will explicitly shape the future of society as well as science, especially concerning our openness to phenomena that challenge our current belief systems.

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