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Does quantum entanglement turn Rowlands' 'principle of duality' into a 'law'?

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Does quantum entanglement turn Rowlands' 'principle of duality' into a 'law'?

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Abstract. Physical laws are permanently observed. They are universal but not proven. Newton's universal law of gravitation and three laws of motion, derived from the observations and theories of Copernicus, Kepler, Galileo and others, were used to take astronauts to the moon and return them safely to earth. Theories about the origin of gravity and whether gravitational forces are fundamental, quantum, entropic, induced, emergent, curved spacetime or fields like electromagnetism are still being probed. General relativity is a geometric theory, not a law, about gravity. In a book called *Zero to Infinity: The Foundations of Physics* Peter Rowlands asserts that physics is "founded entirely on the principle of duality." Wave-particle duality is one of the most fundamental representations of quantum objects. Photons, electrons, neutrinos and even molecules have been shown to be in superposition and entangled. This paper will examine the role that quantum entanglement plays in the fermion/boson relationship of Rowlands' nilpotent Dirac equation. Many other entangled physical dualities, identified as being foundational to physics, strongly suggest that his 'principle of duality' should be promoted into a physical law.

1. Introduction

Recent studies have demonstrated that the wave-particle nature of light exhibits quantum behaviors called superposition and entanglement. Entanglement is one of the most esoteric features of quantum mechanics but it is not exclusively quantum. The laws of thermodynamics declare that energy cannot be created or destroyed, entropy can never decrease and that we cannot cool an object to absolute zero. The ability of quantum particles to share an entangled state, even when far apart, is being harnessed to produce mechanical work may violate the laws of thermodynamics. The question whether the dual wave-particle nature of light can appear simultaneously is also being challenged. The dual nature of light observed in the slit-experiment demonstrates the superposition of both particle-like behavior, single photons from a given slit are detected, and wave-like behavior when interference rings are detected. It was Huygens who first formulated a wave theory of light in 1678 at the Académie des sciences in Paris and published in 1690 under the title Traité de la Lumière (Treatise on Light). Newton also conducted experiments with light and demonstrated its particle nature and calling them corpuscles. The dissimilarities about the properties of light are not completely understood and experimentation continue to this day with unexpected results.

In 1900 Max Planck, while studying black-body radiation, suggested that the observations could be better explained if the energy stored in a molecule was a "discrete quantity composed of an integral number of finite equal parts' and called them "energy elements." Five years later Albert Einstein published a paper in which he proposed that light-related phenomena such as black-body radiation and the photoelectric effect could be modeled as electromagnetic waves as consisting of spatially localized, discrete wave-packets which he called "light quantum" (German: *das Lichtquant*). An experiment in 1915 by Robert Millikan confirmed Einstein's model of the photoelectric effect and he was awarded the Nobel Prize in 1921 for "his discovery of the law of the photoelectric effect." Millikan's Nobel Prize followed in 1923 for "his work on the elementary charge of electricity and on the photoelectric effect."

In 1928 Dirac extended the matrix mechanics of Heisenberg and introduced a 4x4 matrix equation which provided theoretical justification for Pauli spin, implied the existence of antimatter and led to the discovery of the positron. Dirac's union, not unification, of quantum mechanics and relativity represents one of the greatest successes of theoretical mathematical physics. Mathematical modeling and gedankenexperiments have taken center stage in physics for the last 100+ years and the burden today is on experimental physicists who are asked to validate the constructs of their mathematical colleagues. Strings, loops and knots dominate the current geometric models. They truly have mathematical beauty but may not even be physics.

2. The wave-particle nature of light

In 1924 de Broglie proposed that electrons, just as photons, exhibit both particle and wave properties. His thesis was that the momentum equation $h\nu_0 = m_0c^2$ between momentum and wavelength, where h is the Planck constant, is $\lambda = h/p$ and that this relationship holds for all types of matter, microscopic as well as macroscopic. Niels Bohr added the "complementary principle" to de Broglie's theory asserting that photons and electrons exhibit dual qualities but that they are mutually exclusive, i.e. they cannot be measured or observed simultaneously. The almost 250-year old investigations about the nature of light was finally coming to an end. Physicist finally agreed that light has both a particle nature and a wave nature. Another quantum phenomenon, called entanglement, appears to apply to animate objects as well as inanimate objects. Biologists may be leading the way on showing how effects related to quantum entanglement are essential in explaining biology's vital questions. Entanglement has been found linking bacteria and quantized light and may be responsible for photosynthesis, avian navigation (germane to the author's hobby of raising homing pigeons in Texas) and even consciousness. Gravity, regarded as spacetime curvature in general relativity, may itself may turn out to be an entanglement of 'continuous' time and 'discrete' space.

Physicists have not developed a complete theory about the nature of space, time or space-time to whose name einSTein (author's note) will forever be linked. The outstanding question is whether space is discrete or continuous. If space is discrete with a minimum Planck length, then we can throw general relativity out the window. The same question applies to time. Opinions range from reasonable to ridiculous. The author's opinion, open for classification, is summarized in [1]. The main idea in the paper is about the nature of valid theories in physics. The most comprehensive theories in physics are those that incorporate both discrete and continuous variables. The history of light, which has been studied for hundreds of years, is a classic example whose complete description requires both a discrete particle and continuous wave nature. Experiments attempting to exhibit both of those features simultaneously have been conducted. Figure 1, an artist rendition, depicts the entanglement of continuous waves and discrete particles. In 1908 Minkowski mathematically united discrete space and continuous time as a 4-vector utilized by Einstein in special relativity. The union, not unification, of discrete and continuous physical objects appears to be a necessary, and maybe even sufficient, ingredient in developing a complete picture of the physical world.

Can the einSTein Space-Time union be regarded as an entanglement? It appears to be the case. While making a physical measurement a decision has to be made which one is discrete and which one is continuous. A space-like combination requires all physical quantities to be discrete and a time-like combination requires them to be continuous. One view gives us Schrodinger's wave mechanics and the other view gives us Heisenberg's quantum mechanics. Two valid theories, one discrete the other continuous are needed to completely describe the relativistic world. Rowlands [2] clarifies the foundational role that these two properties play in developing physical theories and eliminates many of the paradoxes associated with them. He characterizes space, time, mass and charge as being the four "fundamental parameters of physics" and then combines them into a single nilpotent Dirac equation. The group-theoretic structure in his universal rewrite system is a novel foundational approach to physical reality. As a quaternion model it is a complete packaging of four (dual) physical elements. Two of the parameters are continuous, two are discrete. It is primarily Rowlands' insights into the role that discreteness and continuity play in physical theories that has led to a never investigated foundational approach to physics [3] and laws of nature in general, including the structure of the DNA molecule. The system he creates applies not only to physics and biology but also to mathematics, chemistry, computation and any self-organizing system.

3. Laws of nature

Newton's universal law of gravitation and three laws of motion were published in a 1687 Latin book called *Philosophiæ Naturalis Principia Mathematica*. Now called classical mechanics, to distinguish it from relativistic and quantum mechanics, the laws were used to put two men on the moon in 1969 with one orbiting the moon waiting for their return. Overcoming earth's gravity and manipulating the gravitational forces of the planets in our solar system is called the greatest engineering feat of all times. Many outstanding theories about the origin of gravity and what is meant by *gravitational forces* are still unanswered and the most studied is Einstein's 1916 theory called General Relativity (GR). It is noted by many, including Rowlands [3], that GR is another theory 'about' gravity and not a theory 'of' gravity, meaning it does not explain what gravity is. GR is a geometric theory not a physical law. It could, like any physical theory not falsified, become a law. It was Newton who introduced the idea that physical laws are derivable from other more fundamental laws called principles. We find many physical *principles* in the form of conservation laws and symmetries with respect to time and space.

Laws of nature and scientific theories are never completely verified and it only takes a single counterexample to falsify one. Counterexamples conclusively refute scientific hypotheses, theories, principles and even laws. Recall that it was Copernicus who revised the earlier geocentric *theory* that planets in the solar system revolved around the Earth by reconfiguring the planetary orbits and centering them on the Sun. The geocentric model was abandoned in favor of a more explanatory heliocentric theory.

Newton incorporated principles and theories of Galileo, Kepler and Descartes into what are today called 'Newton's three laws of motion.' It was actually Descartes who modified the geometry of Galileo's principle of inertia to accommodate rectilinear motion rather than the Aristotelian hypothesis of circular motion. They were called laws primarily because they included mathematical formulae that allowed for verifiable calculations. It actually took some two hundred years for Kepler's three laws of planetary motion, published between 1609-1619, to take on its current formulation. In Voltaire's *Eléments de la philosophie de Newton*, published in 1738, we see for the first time the use the word *laws* in reference to both Kepler and Newton's works.

Newton's first law is called the 'law of inertia.' In 1589 Galileo argued experimentally that motion given to a stationary body on a horizontal plane would be perpetual. He explained how a moving body is indifferent to motion or rest in the horizontal plane and that it would remain in the original state it was given. This "principle of inertia" for horizontal motion enabled Galileo to establish a science of dynamics. After his death a more general principle of inertia was formulated by Gassendi and Descartes. Galileo explained how it is possible that on earth, which is spinning on its axis and orbiting the sun, we do not sense its motion! An inertial principle provides the answer. We are in motion with the earth and for that reason it appears to us to be at rest. Newton showed there is no essential difference between rest and uniform motion in a straight line. Both can be regarded as the same state of motion as seen by different observers. Newton extended the Galilean concept of relativity to include observers. His idea accommodated both an inertial principle and the original Galilean principle of relativity. The invention of the Calculus, the mathematics needed for calculating area, velocity and acceleration, replaced

Kepler's geometric laws with differential and integral laws. Gravitational forces would now be linked to acceleration. Newton defined force as being dependent on mass and a change in velocity, **F** = m**a**.

Hundreds of principles and laws can be found in the literature: scientific and non-scientific, mathematical and physical, philosophical and metaphysical. Gauss' Law, the principle of least action, conservation laws, the principle of equivalence, de Morgan's laws, Coulomb's Law, Heisenberg's uncertainty principle and the laws of thermodynamics are appealed to by scientists on almost a daily basis. Students in elementary school are taught the commutative and associative laws of multiplication and addition. Mendel's Laws, Hooke's Law, Bernoulli's Principle and Boyle's law of gases are also well known. Einstein has one law and one principle associated with his name, the law of the photoelectric effect and the equivalence principle.

In physics, laws don't explain the mechanism by which any single phenomenon might occur. Laws, rather, describe the phenomenon that controls the observation. Newton's law of universal gravitation asserts that all material objects attract each other with a force proportional to the product of their masses and inversely proportional to the square of the distance separating their centers. The mathematical statement of the law $F = GmM/r^2$ allows us to make calculations and accounts for empirical observations and phenomena related to objects that move on the earth and in the cosmos. It is a universal law.

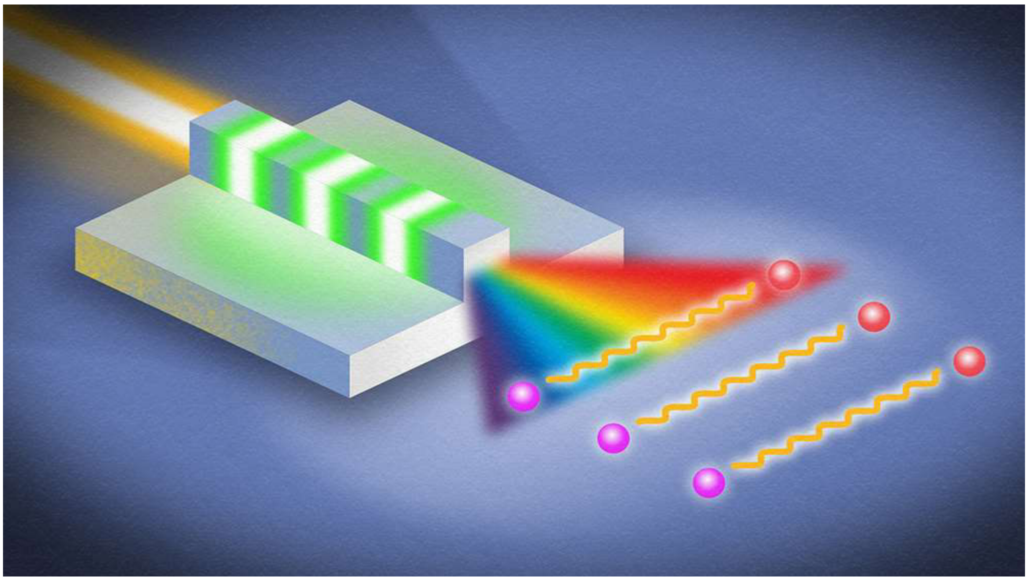

Figure 1. This artist rendition by researchers U. Javid and M. Osadciw in the lab of Qiang Lin at the Univ. of Rochester in New York depicts ***entangled photons***.

The language and rules of mathematics depend on logical manipulation of well-defined symbols. Symbolic logic depends on validated and mutually agreed upon postulates and axioms. Using definitions, primitives and the set of axioms we draw logical consequences called theorems which demand rigorous proofs. We can prove a theory in mathematics. We cannot prove a theory in physics but it is a mandatory to do so in mathematics. Many different geometries exist, some Euclidean some non-Euclidean. All are based on different sets of axioms. The geometric and mathematical axioms allow us to prove theorems. The commutative law of natural and real numbers also applies to imaginary numbers but not to quaternions. The associative law applies to all of them except octonions. In fundamental physics, axioms are called principles. Principles in physics are not proved and only remain principles if they are never experimentally violated. Once a principle has been established through repeatable observations and experiments, and never falsified, it can become a law.

4. Entanglement

Entangled systems, as demonstrated among photons and electrons, means that their quantum states are not individual particles but act as an inseparable whole. In entanglement, one entity cannot be fully described without considering the other entity. The state of a whole system is always expressed as a superposition of both entities. Entanglement is broken when the entangled particles experience decoherence through interaction with the environment. This happens when a measurement is taken. Many experiments have been conducted demonstrating that entanglement can be entropic and measurement-induced, electrically-induced (EIE), and even gravitationally-induced (GIE). It is the gravitational action induced by an elastic spacetime introduced by Sakharov and discussed in [4] that suggests that spacetime curves matter rather than the other way around as presented in general relativity.

Studies and experiments in entanglement support the idea that the laws of thermodynamics depend not only on classical phenomenon and information but also on quantum effects. Entangled states are utilized to extract thermodynamic work beyond classical correlation using feedback control and thermal fluctuations. This may be the same phenomenon that occurs in the Planck scale zero-point fluctuations where quantum inertial forces operate to produce emergent space-time. The underlying duality, identified by Rowlands, which is more fundamental than the wave-particle nature of photons and electrons or other quantum objects is discreteness/continuity. Figure 3, a modification of Table [2, p 232], shows the continuous and discontinuous (discrete) approaches to physics. It also applies to the calculus, the mathematics of motion. Leibnitz differentials were based on discrete space and Newton fluxions were based on continuous time.

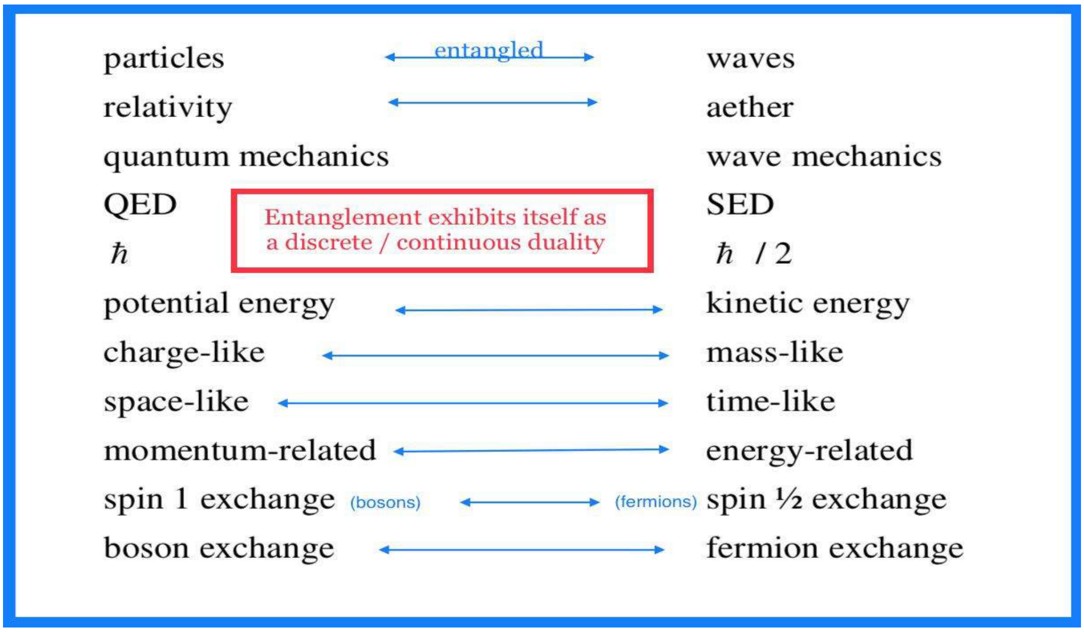

Figure 2. Fundamental physics depends on continuous and discrete approaches

5. The factor 2 in discrete/continuous phenomenon

Rowlands' principle of duality differs from the standard view in physics where duality means an equivalence between different, or complementary, descriptions of the same physical system. The prototypical example is electric–magnetic duality. Mathematically speaking the term isomorphism, meaning a one-to-one correspondence, is more descriptive. In physics, just as in mathematics, 'duality' does not have an agreed upon definition but two independent theories exist which look different but can be mapped to each other. A dictionary, of some sort, pairs the concepts in one theory to the concepts in the other theory. Rowlands' investigation into the foundations of physical laws and his 'principle of duality' have resolved many of the paradoxes in physics and has shown why *grand unification*, but not unity, in physics may be impossible. It is grounded on the idea of continuity and discreteness. Many of Rowlands' papers are readily available online and only his 2007 and 2014 books are provided as references. According to his theory a dualistic relationship exists between gauge the and gravity. It is different from the duality theorized by the AdS/CFT correspondence. Some view the holographic duality and CFT leads to Newton's first law of motion and the universality of gravity is derived from entanglement entropy. Rowlands states it this way, "Gravity/gauge theory correspondence appears to show that gravity acts as a dual to the combined gauge theories of the electric, strong and weak interactions, and duality in our language usually refers to negation and totally zero [3, p. 148]."

The factor 2 is a link between the discrete and continuous domains in many unrelated phenomena. Figure 2, a modification of Table [3, p 211], are examples in several physical domains. The factor 2 and its emergence in the four parameter group (space, time, mass, charge) also highlights the interdependence of continuous and discrete events. The three essential dualities four fundamental parameters are conserved/nonconserved, imaginary/real, commutative/anticommutative. The factor 2 can result from action and reaction (A); commutation relations (C); absorption and emission (E); object and environment (O); relativity (R); the virial relation between potential and kinetic energy (V); or continuity and discontinuity (X). The fermion/boson spin relationship fits well into this schema when written as a fermion/antifermion duality produced as particle-antiparticle pairs in the vacuum. The boson/fermion pairs never separate and move in the same direction. Their wave functions do not spread and they move at the speed of light. A boson mapping to a pair of fermions can also be inverted. A single fermion can be mapped to a coherent state of bosons. The boson-fermion symmetric duality has been shown to be exact.

"The factor 2 reveals that it is the link between the continuous and discrete physical domains and is also an expression of the discreteness of both material particles (or charges) and the spaces between them, as opposed to the continuity of the vacuum in terms of energy [3, p. 211]."

Kinematics						V	X	
Gases	A						V	
Orbits							V	X
Radiation pressure				E			V	
Gravitational light deflection						R	V	
Fermion / boson spin			D		O	R	V	
Zero-point energy	A	C					V	X
Radiation reaction	A			E		R	V	
SR paradoxes	A			E				

A	action and reaction	O	object and environment
C	commutation relations	R	relativity
D	dimensionality	V	virial relation
E	absorption and emission	X	continuity and discontinuity

Figure 3. The numerical factor 2 appears in many unrelated physical processes

The explanations overlap in the case of individual phenomena but also may be part of "some more general process." The more general process that Rowlands intimates may be that mysterious relationship called *entanglement* that discrete objects and continuous fields seem to exhibit in their interactions. Not only does it provide insight into the slit-experiment and wave-particle interaction but it also applies to the relationship between 'discrete inertia' and 'continuous gravity.' Newton's third law of motion is useful in understanding the inertial-gravitational interaction and the equivalence principle as has been argued in [4]. In the most general terms, Rowlands asserts that, "the factor 2 is an expression of the fundamental duality in the whole concept of 'nature'." These ideas will be presented at the first international symposium dedicated to "Laws of Duality in Biology, Mathematics and Physics" in 2023.

6. Rowlands' 'principle of duality'

The three essential *dualities* identified by Rowlands are central to the history of physics but never classified as being dualities. The continuous/discrete duality is obvious when making a distinction between potential and kinetic energies. Another distinction manifests itself as a duality between conserved and nonconserved quantities which are related to fixed and changing conditions. The duality is also seen when making a distinction between space-like and time-like theories, as in the Heisenberg and Schrödinger formulations. The duality is obviously seen when discussing quantum mechanics and stochastic electrodynamics. Regarding space as being and time as being continuous, but also entangled, fit very well into this schema.

Rowlands' nilpotent Dirac state vector combines both mathematical and physical dualities incorporating the four fundamental parameters space, time, mass and charge. Half of the parameters are continuous; the other half are discrete ($\pm\, \boldsymbol{ik}\mathrm{E} \pm \boldsymbol{i}\, \mathbf{p} + \mathbf{j}\, \mathrm{m}$). We can regard the representation as being either a classical object or as the state vector for a fermion in relativistic quantum mechanics depicted in the Dirac equation. The instantaneous entanglement of all nilpotent fermion state in the vacuum and the nonlocal connection between all the state vectors in the entire universe can be described mathematically in terms of Hilbert space. Rowlands summarizes this foundational structure in the following sentences. "Since the universe is believed to be composed entirely of fermions or fermion-antifermion combinations (bosons), the Dirac equation is, in the final analysis, the most significant way of incorporating the foundational basis for the whole of physics into a single structure, and it would appear that it is itself founded entirely on the ***principle of duality***. Ultimately, it would seem, duality is not merely a 'component' of physics but an expression of the fundamental nature of physics [2, p.443]."

7. Summary

De Broglie's 1924 thesis was not experimentally confirmed until 1927 but it was his 1925 pilot-wave model and discovery of the wave-like behavior of particles that was used by Schrödinger to formulate wave mechanics. The pilot-wave model and its interpretation was revived and enhanced in 1952 by Bohm. The Schrödinger equation was a pure mathematical entity and had a probabilistic interpretation, without any insight of any real physical element. Mathematical theories, since the appearance of non-Euclidean geometries of the late 1800s, continue to be the most relevant in physical studies. The trend continues to the present day and some lament the forty-year careers they dedicated to string theory, its geometry and its mathematics have become resistant to solvability and even derivability.

It was in the studies of the nature of X-ray radiation that de Broglie built a theory linking particle and wave representations. He concluded that the particle velocity was equal to the group velocity of phase waves. It was also known that the particle moved along the normal to surfaces of equal phase. In the general case the trajectory of the particle could be determined by using Fermat's principle (for waves) or the principle of least action (for particles). This was a clear indication that a connection between geometric optics and classical mechanics existed. For de Broglie the generalization was only statistical and he did not accept the idea that "the particle must be the seat of an internal periodic movement and it must move in a wave in order to remain in phase with it was ignored" adding that it is "wrong to consider a wave propagation without localization of the particle, which was quite contrary to my original ideas."

De Broglie extended the principle of wave–particle duality to all matter, applying to crystals and their effects of diffraction as well. His principle of duality extends to many laws of nature and should probably be called a law rather than a principle. Likewise, Rowlands' characterization of three dualities as being foundational to the laws of physics is without precedence. Ultimately, the inherent dynamics of entanglement sets limits to the thermodynamics when transitions from the discrete to continuous ones are hypothesized. Entangled dualities may complete the system of mechanical laws. It is in this sense that entanglement may turn Rowlands' 'principle of duality' into a physical law.

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