Conceptual Article

A physical basis for entanglement in a non-local hidden variable theory

Dirk J. Pons [1], Arion D. Pons [2] and Aiden J. Pons [3]

[1]Author to whom correspondence should be addressed Department of Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch 8020, New Zealand, Email: dirk.pons@canterbury.ac.nz
[2]University of Cambridge, Cambridge, UK.
[3] University of Canterbury, New Zealand

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Abstract

Problem: Superposition and entanglement are coherent effects, which can be quantified by quantum mechanics (QM), but lack descriptive explanations. They are typically analysed with inequality methods, and the results favour QM and reject physical realism and hidden-variable solutions. In particular, Colbeck & Renner (2011) showed that no extension of quantum theory can exist with better predictive power than quantum mechanics itself. **Purpose:** The purpose here is to critically evaluate from a conceptual and philosophical perspective the ontological underpinnings of the inequality approach. The current work is speculative in nature as it is based on a conjectured non-local hidden-variable (NLHV) design for particles, and does not yet have a mathematical formalism. Nonetheless this is worth attempting for the philosophical questions it poses about the nature of reality, and the pointers it gives to possible future directions in fundamental physics. **Findings:** The premises of the C&R proof (that particles are points, that locality exists, that quantum theory is correct) are inconsistent, hence invalidate its conclusion. We also show that superposition and entanglement may be qualitatively explained if particles were to have the internal structure proposed by the Cordus NLHV theory. **Originality:** The ability to explain superposition and entanglement conceptually in terms of physical realism is relevant because it rebuts the claim that it is impossible that such a hidden-variable theory could exist. This is significant because previously it has been believed that these phenomena are explainable by QM only.

Keywords: non-local; superposition; entanglement; coherence

1 Introduction

The scientific method is built on the premise that relationships of causality will be underpinned by physically real mechanisms. A theory is incomplete if it does not explain all the relationships, or does not identify the underlying mechanisms in physical terms. Typical phenomena that are difficult to explain in these terms are superposition and entanglement. These are the focus of this paper. This paper argues for the restoration of the primacy of physical realism. It does this by rebutting existing claims for the privileged position of QM, and showing that it may be feasible to construct a deeper conceptual theory for fundamental physics based on physical realism.

In the present context *physical realism* refers to a philosophical position about causality: that physical observable phenomena do have deeper causal mechanics involving the interaction of parameters, and that these parameters exist objectively [1]. It is different to *scientific realism* which has an epistemic basis in accepting that scientific theories are at least approximately true. This is also not the same as *local realism,* which posits a realist interpretation but with locality. *Locality* is the expectation that a point object is only affected by the values of fields and external environmental variables at that point, not by remote values. Locality has also come to mean that a remote disturbance travels to the point of interest by at most the speed of light [2]. In contrast *non-locality* posits that particles are affected by remote events, and the transmission of cause and effect may be superluminal.

2 Background

Quantum mechanics proposes that elementary particles are zero-dimensional (0-D) points, without internal structure of any kind. Yet paradoxically QM also assigns attributes of spin, charge, mass, etc. to these same points. These *intrinsic variables* must then somehow aggregate and scale up, in ways poorly delineated, to describe the mechanics of the macroscopic level.

There are multiple interpretations of quantum mechanics that seek to address this problem. These include the Copenhagen interpretation, many-worlds theorem, objective spontaneous collapse theory, and the de Broglie-Bohm pilot-wave theory. Each seeks to connect quantum principles to a form of physical realism, but each has limitations. A philosophical criticism is that they achieve epistemic rather than ontological explanations. Consequently there remains a disconnect between the formulation of quantum theory and its groundings in physical realism. Another unsolved problem is the lack of external validity - no quantum theory, including quantum chromodynamics, explains the structure of even the atomic nuclei, nor the structure of matter, nor general relativity and gravitation. It does not scale from the fundamental to the macroscopic level. Quantum mechanics provides an empirically validated theory. However is not ontologically sufficient as it is unable to describe how the causal mechanisms operate.

Historically there was an expectation that some of these weaknesses might be overcome by an alternative physics based on some hypothesised structure at the sub-particle level, i.e. rejecting the QM premise that particles were 0-D points. Such a physics might be constructed on the basis that observed behaviours were caused by parameters that were not distinguishable at the particle level, hence a hidden-variable (HV) theory, as per the Einstein, Podolsky and Rosen (EPR) position [3]. The first such attempt was the de Broglie-Bohm theory [4, 5] of the pilot-wave, but it has not progressed much beyond an interpretation of the wavefunction. It has not contributed to cosmology nor formed a general theory of physics. It might be said that the de Broglie-Bohm theory is already able to explain entanglement behaviours. However it is not a theory based on physical realism, because the theory proposes that the wavefunction and guiding function are physical, but fails to offer a mechanics of causality whereby this functionality might arise from deeper parameters that plausibly might exist objectively.

Nonetheless the possibility exists that other solutions might exist in the HV sector. If so, the answer is not obvious and the sector has generally been unproductive. The difficulty is to identify what the physical structures might be at the sub-particle level, and the underlying mechanisms of cause and effect.

Consequently there has been another line of research to evaluate whether hidden-variable theories are permitted on theoretical grounds, and isolate those sub-theories that are non-viable. This effort started with Bell [6] wherein a mathematical *inequality* approach was devised to test the viability of hidden-variable theories. This and subsequent contributions, e.g. [7, 8], showed that *local* hidden-variable solutions were non-viable. However this line of work has been inconclusive. The issue is that the inequalities do not preclude all *non-local* hidden-variable (NLHV) solutions. However there is also a dearth of candidate NLHV solutions to evaluate. It is not obvious how such a theory could be constructed in the small residual space permitted by the inequalities.

A more recent application of the inequality method found in support of quantum mechanics: Colbeck & Renner (C&R) claimed that no extension of quantum theory can exist with better predictive power than quantum mechanics itself [9]. Those authors interpreted their results as favouring the stochastic interpretation of quantum mechanics: '*any attempt to better explain the outcomes of quantum measurements is destined to fail*' (p4). That interpretation implies that everything exiting at the fundamental level is already described by QM. However there is a need to evaluate the robustness of these claims, and explore the implications for the further development of fundamental physics.

3 Purpose and approach

The purpose of this work was to evaluate NLHV theory for the ability to explain entanglement phenomena. The approach has two parts. The first used logical inference to evaluate the coherence of the C&R work, by comparing the conclusions to the premises. The benefit of this approach is that it takes a holistic perspective that scrutinises the premises underpinning the mathematical formalisms.

The second part was to develop a hidden-variable explanation for superposition and entanglement. C&R felt it was impossible that there could exist a hidden-variable theory per EPR [3] that explains the indeterminism whereby '*measurements generate random outcomes*' (p1). Finding such a hidden-variable solution would rebut the C&R proof. In seeking to develop such a theory we eliminated the *local* hidden-variable designs as intrinsically unsuited to explaining the non-local behaviour of physical systems, immaterial of whether or not the inequalities actually prove this. This is because a realist perspective is to accept that entanglement is an empirical truth. Consequently the solution needs to be a *non-local* hidden-variable (NLHV) design. This paper applies one such theory, the Cordus theory [10], and shows that it can conceptually falsify the C&R proof.

4 Results

The empirical results of entanglement tests validate the predictions of the inequalities: locality does not apply at the particle level. Hence by inference of scientific realism, fundamental physics cannot be adequately represented by any theory based on locality.

4.1 Critique of the Inequality method

The inequality method makes premises about the nature of what is initially accepted as true. These philosophical constructs are then adapted into mathematical formulations. The method then proceeds by further processing the formulations. It then extracts mathematical inferences, and transfers these back to create insights about the physical world. The inequality methods provide a comprehensive mathematical treatment, but to be logical consistent the initial semantic premises must be unbiased regarding the various theories under scrutiny; the formulation must faithfully represent the premises; the insights gained must be compared against the premises to eliminate findings based on circular reasoning.

We do not take issue with the mathematical treatment – instead we show that there are issues with the logical construction and that these have contrary implications not considered in the original work. First is the problem of trivial outcomes. The inequality approach leads to the conclusion that hidden variable theories cannot have local parts, e.g. [6-8, 11]. However it is self-evident that any theory based on *locality* would be unable to explain entanglement, since the latter is inherently *non-local*. To use a mathematical formalism to come to this point is to over-work the problem.

Second is the problematic null hypothesis of the general approach. The inequalities assume from the outset that QM is correct, and then seek confirmation thereof. Most applications of the method have this problem including recent applications [9], with some exceptions [12, 13]. This weakens the construct validity of the conclusions.

Third, all the existing inequality approaches have the problem of framing. They force the subject matter into a quantum framework, by only admitting zero-dimensional (0-D) point particles to the question. Hence they only test between QM, versus theories with 0-D point hidden variables. This is a major shortcoming because hidden variable theories are not limited, as is QM, to 0-D point constructs. The inequalities have not tested against the possibility that a non-0-D point formulation of a hidden-variable theory might exist. Consequently the inequalities merely show that 0-D point particles are incapable of having internal structure. This is a trivial outcome given that a zero-dimensional point cannot, by definition, have internal structures.

In summary, the inequality method suffers from restrictive premises that compromise the validity of its conclusions. The only reliable inference that can be made is that physical realism and hidden-variables are incompatible with the 0-D point premises of QM. The inequalities do not exclude the possibility that particles have internal structure.

4.2 Rebutting the C&R argument

In the specific case of the C&R argument [9], the proof was based on three key assumptions, each of which is now examined. Those premises were: (1) that particles are zero-dimensional (0-D) point particles, this being an intrinsic premise of quantum theory, (2) that locality prevails - '*the outcome, X, of a measurement is usually observed at a certain point in spacetime*' (p2), and (3) that quantum mechanics is correct - '*We additionally assume that the present quantum theory is correct'(p2*).

Each of these is unproven as a universal truth. First, while it is true that quantum theory assumes that particles are 0-D points, there is no reason to hold this as a necessity of physics. The absence of evidence of structure at the sub-particle level is not evidence that particles have no sub-structure. The fallacy is an *argument from silence (absence)* of evidence.

Since the proof is premised on 0-D points, its results do not necessarily apply to theories where particles have size and internal physical structures. The framing problem is also evident in that C&R elsewhere interpret hidden variable solutions as being based on random stochastic processes: '*In a hidden variable model, one attempts to describe the outcomes of such measurements by assuming that there is a hidden random variable Γ, specified by some probability distribution* $P_Γ$' [11] (p1). This is erroneous, because hidden variable solutions are not necessarily *random* or probabilistic. The one shown below, the Cordus theory, proposes that the internal mechanics are deterministic. The external manifestation does show a probability distribution but this is because of the limited measurement capacity of the external observer, and need not be due to intrinsic random variability. Hence the C&R premises do not include a reasonable representation of hidden-variable models. They wrote: '*we have shown that the randomness is inherent: any attempt to better explain the outcomes of quantum measurements is destined to fail*' [9](p4). From the NLHV perspective the apparently stochastic nature of phenomena is not a fundamental feature of reality (the randomness is not inherent) but is instead an artefact of the 0-D premise of quantum theory.

The second C&R assumption is that locality *does* prevail regarding effects happening at a point in spacetime. This is a common assumption of the inequality methods, e.g. [2]. This is incongruent given that the contrary premise is simultaneously assumed, that superposition and entanglement are real phenomena, hence that locality *does not* prevail. Consequently the findings of the proof are based on conflicting starting premises.

The third assumption is that QM is basically correct. This is logically problematic given that it led to the eventual conclusion that '*quantum theory really is complete*' (p3). Hence the proof assumes its conclusion as a premise. It might be argued that initially accepting the veracity of QM is not circular reasoning, because the inequality method was merely seeking to explore whether quantum mechanics could be extended to deterministic hidden variables. However this will not do, since an overly restrictive construct was adopted for what such hidden-variable solutions might comprise.

What the C&R inequalities actually proved is that quantum theory *cannot be extended* to better explain reality *while* it holds to those three premises (particles are points, locality exists, quantum theory is correct).

4.3 Is quantum theory incapable of improvement?

The C&R proof is also capable of a contrary interpretation: that quantum theory is incapable of being expanded into a general theory for fundamental physics. There are several grounds for this statement, the first being ontological incongruence: we have been assured that QM is complete, yet it is manifestly unable to explain all phenomena, and therefore cannot be a complete or ideal theory. This criticism cannot be evaded by claiming that QM is still complete when physical realism is abandoned, because QM is incomplete in other ways that have nothing to do with physical realism. Examples are the inability to explain how the strong force causes the nuclear attributes of stability and instability (the problem of explaining the table of nuclides), the inability to explain the origin of mass (the Higgs mechanism only explains one small aspect of mass), and the lack of a quantum explanation of gravitation (the problem of unification). Even at its outset the completeness of quantum mechanics was challenged, the EPR argument being that ‘the description of reality as given by a wave function is not complete’ [3], and this situation persists.

Additionally the proof –to the extent that its premises validly represent QM, which appears to be the case - shows that quantum theory has no further room for improvement. This implies that QM is ontologically closed and incapable of representing any new physics or extension. This is a serious implication, given that new physics of some sort must exist, even if only to integrate gravitation. So the C&R work unexpectedly implies that quantum mechanics itself is a non-viable theory under its own premises.

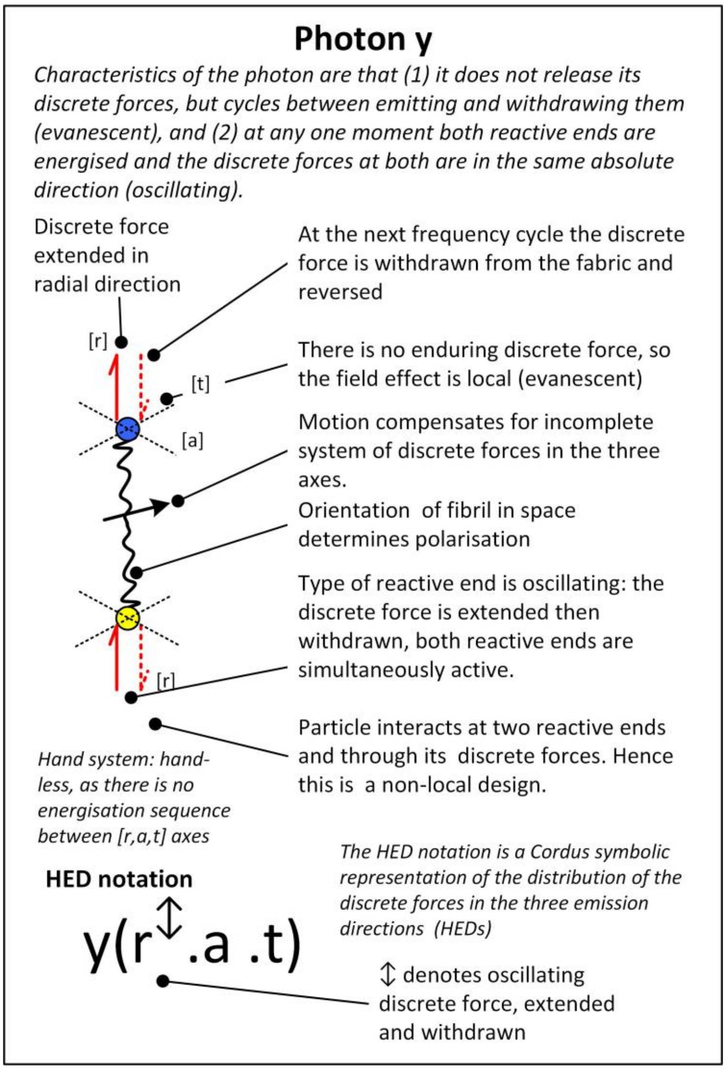
The corollary is that if a new deeper physics does exist it would *not* be quantum theory or even an extension thereof.

4.4 Design of a hidden-variable theory

Next we show that a hidden variable theory *does* exist that can explain why ‘*measurements generate random outcomes*’ (p1). This has otherwise been the preserve of quantum mechanics.

The specific hidden variable theory under examination is the Cordus theory, a conjectured new theory of physics which predicts an internal structure for fundamental particles. This is a NLHV design with the addition of discrete fields. The structure was determined by application of design principles and requisite variability to the double-slit device [10]. The theory proposes that the sub-structure comprises two reactive *ends* that are energised in turn, connected by a fibril, and which emit discrete forces at each cycle of energisation [10]. The discrete forces are emitted orthogonally into space. Their inward/outward propagation direction determines the charge, and the handedness of the energisation sequence determines the matter-antimatter attribute [14]. This is called a *particule* where it is necessary to differentiate it from the 0-D point construct of QM. The theory has been extended since first published, and the original concept remains the same but has been refined. The representation of the photon is shown in Figure 1, electron in Figure 2, antielectron in Figure 3, and neutrino in Figure 4. These are elaborated elsewhere, e.g.

photon [15], proton [16], neutron [17], and neutrino-species [18]. In all these diagrams the basic idea is apparent: the two reactive ends and the fibril. The theory proposes that the origin of particle identity is the discrete force emission. The primary difference is the number of discrete forces emitted, the direction thereof, and the nature of the emission. The theory requires that the photon extends and withdraws its discrete forces, whereas the other particules release theirs into the external environment. The theory makes a specific prediction for the mechanism for matter-antimatter species differentiation [14]. It is conjectured that the energisation sequence, which corresponds to the handedness, is the structural variable. The theory also offers an explanation for the selective spin characteristics of the neutrino species [17]. These details are elaborated further in the references.



Photon y

Characteristics of the photon are that (1) it does not release its discrete forces, but cycles between emitting and withdrawing them (evanescent), and (2) at any one moment both reactive ends are energised and the discrete forces at both are in the same absolute direction (oscillating).

Discrete force extended in radial direction

At the next frequency cycle the discrete force is withdrawn from the fabric and reversed

There is no enduring discrete force, so the field effect is local (evanescent)

Motion compensates for incomplete system of discrete forces in the three axes.

Orientation of fibril in space determines polarisation

Type of reactive end is oscillating: the discrete force is extended then withdrawn, both reactive ends are simultaneously active.

Particle interacts at two reactive ends and through its discrete forces. Hence this is a non-local design.

Hand system: hand-less, as there is no energisation sequence between [r,a,t] axes

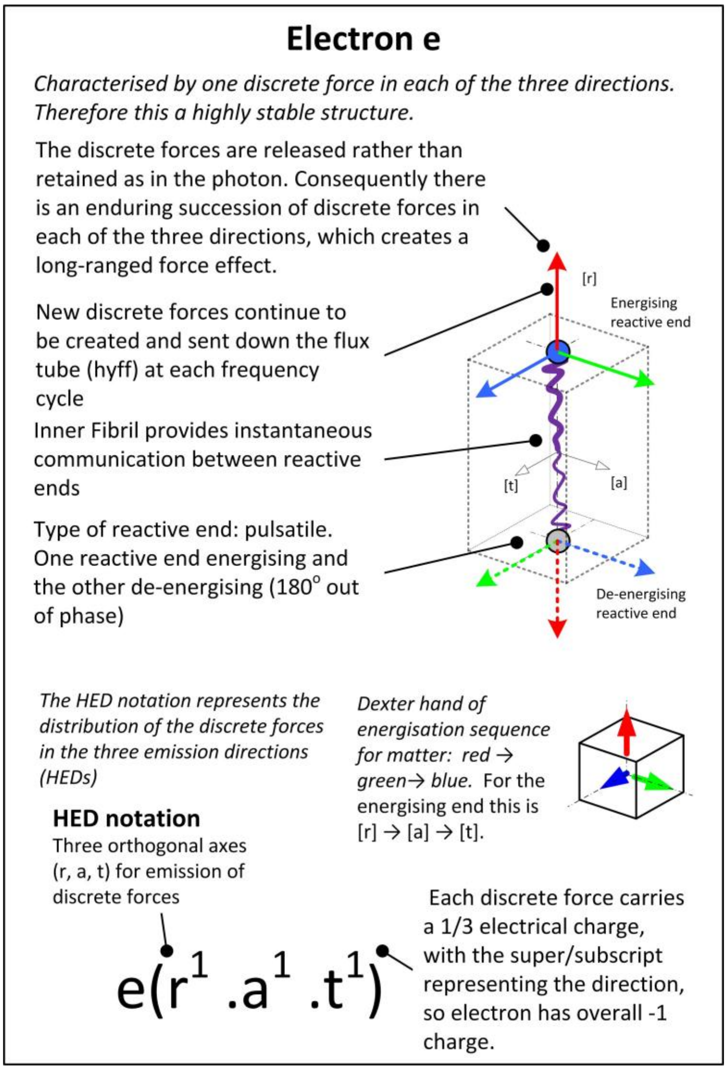
HED notation

$$y(r^{\updownarrow}.a\ .t)$$

The HED notation is a Cordus symbolic representation of the distribution of the discrete forces in the three emission directions (HEDs)

↕ denotes oscillating discrete force, extended and withdrawn

Figure 1: Cordus theory for the internal structure of the photon, and its discrete field arrangements. The photon has a pump that shuttles energy outwards into the fabric. Then at the next frequency cycle it draws the energy out of that field, instantaneously transmits it across the fibril, and expels it at the opposite reactive end. Adapted from [19].



Electron e

Characterised by one discrete force in each of the three directions. Therefore this a highly stable structure.

The discrete forces are released rather than retained as in the photon. Consequently there is an enduring succession of discrete forces in each of the three directions, which creates a long-ranged force effect.

New discrete forces continue to be created and sent down the flux tube (hyff) at each frequency cycle

Inner Fibril provides instantaneous communication between reactive ends

Type of reactive end: pulsatile. One reactive end energising and the other de-energising (180° out of phase)

The HED notation represents the distribution of the discrete forces in the three emission directions (HEDs)

Dexter hand of energisation sequence for matter: red → green→ blue. For the energising end this is [r] → [a] → [t].

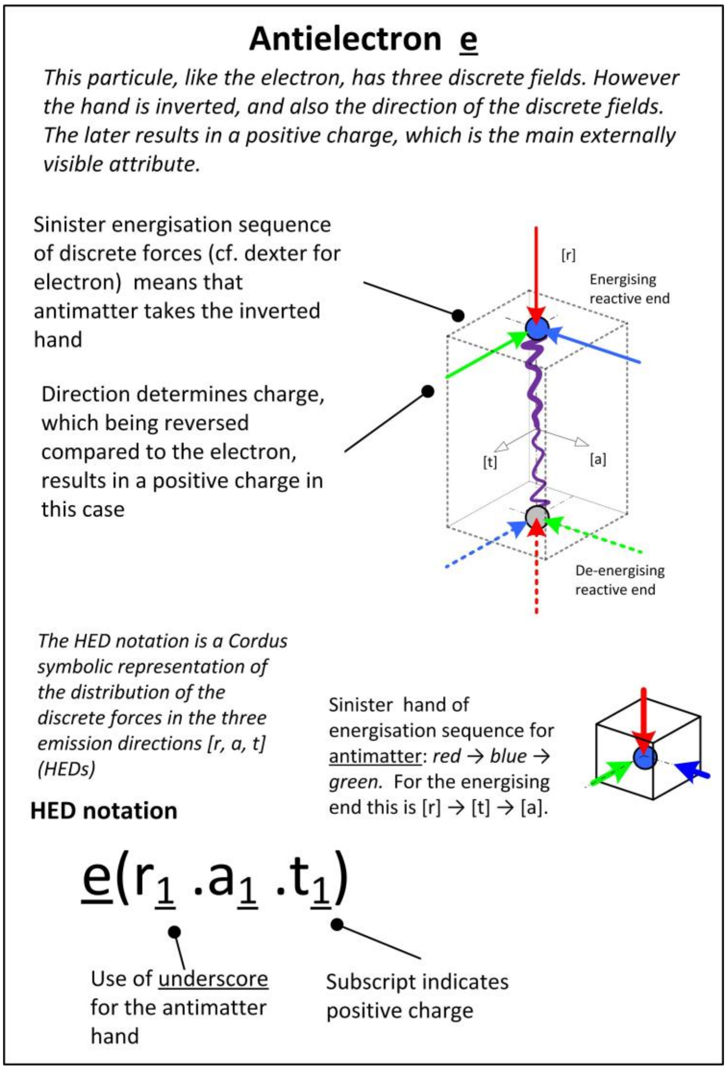
HED notation

Three orthogonal axes (r, a, t) for emission of discrete forces

$$e(r^1 .a^1 .t^1)$$

Each discrete force carries a 1/3 electrical charge, with the super/subscript representing the direction, so electron has overall -1 charge.

Figure 2: The representation of the electron's internal and external structures. It is proposed that the particle has three orthogonal discrete forces, energised in turn at each reactive end. Adapted from [20].



Antielectron $\underline{e}$

This particule, like the electron, has three discrete fields. However the hand is inverted, and also the direction of the discrete fields. The later results in a positive charge, which is the main externally visible attribute.

Sinister energisation sequence of discrete forces (cf. dexter for electron) means that antimatter takes the inverted hand

Direction determines charge, which being reversed compared to the electron, results in a positive charge in this case

The HED notation is a Cordus symbolic representation of the distribution of the discrete forces in the three emission directions [r, a, t] (HEDs)

Sinister hand of energisation sequence for antimatter: *red → blue → green.* For the energising end this is [r] → [t] → [a].

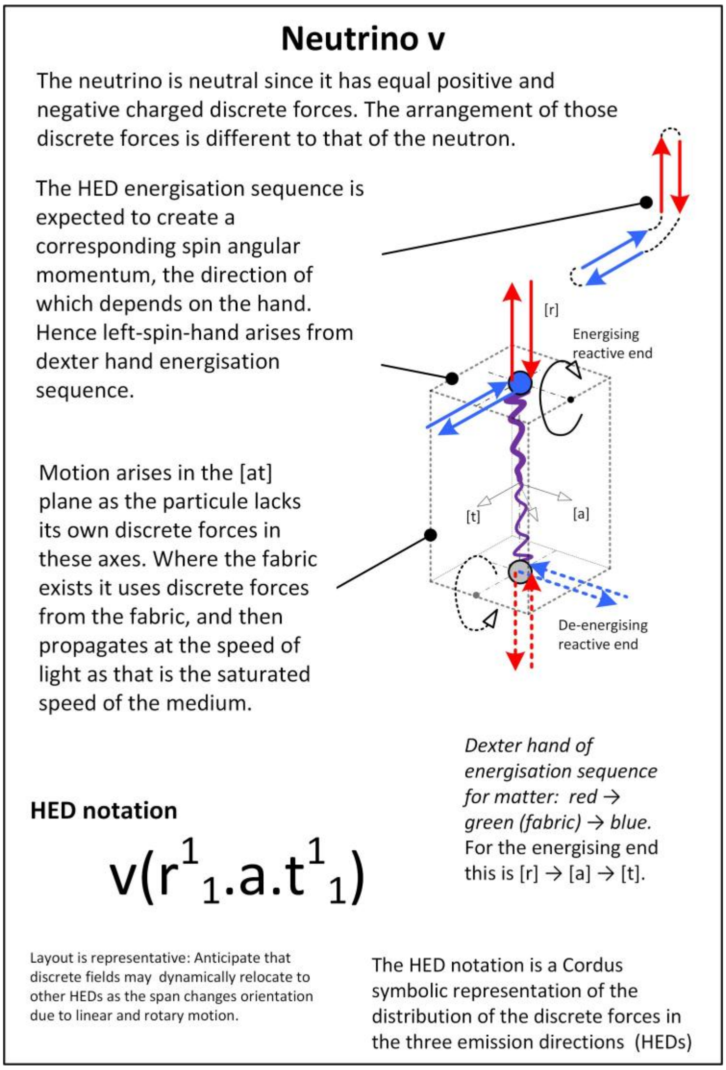
HED notation

$\underline{e}(r_{\underline{1}} .a_{\underline{1}} .t_{\underline{1}})$

Use of underscore for the antimatter hand

Subscript indicates positive charge

Figure 3: The representation of the antielectron as per the Cordus theory. The antimatter attribute, which is opposite to that of the electron, arises from the handedness of energisation sequence of the three orthogonal discrete forces. The charge is also opposite to that of the electron, and this arises as the direction of the discrete forces is also reversed. Adapted from [21].



Neutrino v

The neutrino is neutral since it has equal positive and negative charged discrete forces. The arrangement of those discrete forces is different to that of the neutron.

The HED energisation sequence is expected to create a corresponding spin angular momentum, the direction of which depends on the hand. Hence left-spin-hand arises from dexter hand energisation sequence.

Motion arises in the [at] plane as the particle lacks its own discrete forces in these axes. Where the fabric exists it uses discrete forces from the fabric, and then propagates at the speed of light as that is the saturated speed of the medium.

Dexter hand of energisation sequence for matter: red → green (fabric) → blue. For the energising end this is [r] → [a] → [t].

HED notation

$$v(r^{1}_{1}.a.t^{1}_{1})$$

Layout is representative: Anticipate that discrete fields may dynamically relocate to other HEDs as the span changes orientation due to linear and rotary motion.

The HED notation is a Cordus symbolic representation of the distribution of the discrete forces in the three emission directions (HEDs)

Figure 4: Predicted structure of the neutrino. This physical structure also conceptually explains why this particle must have motion, and why its direction of spin is coupled to the matter-antimatter attribute. Adapted from [22].

The theory explains that bonding occurs between particules by the co-location of one reactive end from each particule, with the synchronisation of emissions [16]. In this way the strong nuclear force is explained as a synchronisation effect between coherent states of matter. The synchronisation may be in or out of phase (cis- or trans-phasic). The bonding is advantageous to the constituent particules to the extent that the combined emissions more completely service the three emission directions. This principle may be extended to an explanation for bonding of protons and neutrons in the atomic nucleus [23].

4.5 Explanation of quantum phenomena

The Cordus theory is relevant to the problem under examination because it explains several phenomena that were previously thought to be only explainable with quantum mechanics. At this stage the explanations are qualitative.

Superposition

The non-local behaviour, hence superposition, is evident in the Cordus particle existing in two places at once, namely at its reactive ends. See Figure 1. Hence the phenomenon of superposition can be qualitatively explained [10]. From his perspective the particule really is in two geometric locations at once: each of its reactive ends is in a different location. The theory predicts that there is no limit to the extent to which the span of the photon may be stretched, whereas the massy particules such as the electron have a constraint linked to frequency.

Wave-particle duality

QM uses a complementarity principle: that photons have multiple properties that are contradictory. QM assumes that wave and particle duality means that both are simultaneously in existence, that the photon is truly a both a wave and a particle at any instant in time. In contrast for the Cordus theory the particule is neither a wave nor a particle, but may be perceived to be either depending on how the measurement is conducted. The theory explains wave-particle behaviour in the double-slit device [10], including blocked-slit outcomes. This is another phenomenon that classical mechanics cannot explain and which was previously thought to be the sole preserve of QM. The Cordus theory explains contextual measurement, which is otherwise difficult to explain with QM.

Locality

The Cordus theory explains that locality fails because the particule is affected by what happens at *both* reactive ends, and by the externally-originating discrete forces it receives at both locations. A *principle of Wider Locality* is proposed, whereby the particule is affected by the values of external discrete forces (hence also conventional fields) in the vicinity of both its reactive ends. However the wider locality effect is only evident at the smaller scale, and hence point-based locality is still approximately applicable at the macroscopic level and at the scale of QM.

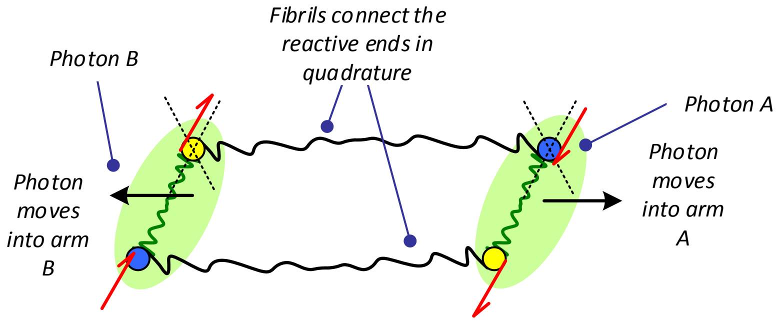
Uncertainty principle

A key explanatory concept in quantum mechanics is that of particles being wave-packets that represent the probability of finding the particle in that place. The QM explanation of the Heisenberg uncertainty principle is that the position of the particle is indeterminate as it could be anywhere along the wave packet. Hence compressing the wave packet to reduce the indeterminacy in position will change the wavelength and therefore the momentum, and thus make the momentum indeterminate, and the converse. The uncertainty principle is typically expressed in terms of the product of the standard deviations of position and momentum.

The explanation from the Cordus theory is that there is no single point that defines the position of the particule. Its reactive ends between them occupy a volume of space, and its discrete fields extend out to occupy a volume of space external to the reactive ends. The causal connection between these internal and external volumes is always maintained, by the energisation frequency behaviour. It is possible to compress the particule spatially, e.g. by the application of external fields to decrease the span between the reactive ends, but this changes the frequency of energisation (increases it for this case). The frequency determines the mass of the particule. Hence an attempt to change the geometric size of the particule (distance between reactive ends) will change its energy. The original energy becomes indeterminate. The Cordus theory therefore qualitatively recovers the uncertainty principle, and proposes that at the deeper level there is a mechanics that couples the frequency behaviour, geometric position of reactive ends (size and location), energy & mass, and emitted fields.

Entanglement

Entanglement may be explained by the Cordus theory as two photons (four reactive ends) being assembled with the pair of reactive ends of the one photon being matched with those of the other. This is proposed to occur via the synchronous emission of discrete forces at each reactive end. The fibrils of the photons keep all four reactive ends synchronised. The assembly is therefore a whole, not two independent particles. Hence sending one matched pair of reactive ends (*one end from each of two photons*) to a remote location merely extends the fibrils. Subsequent changes to any of the reactive ends are transmitted to all the others. This occurs via the fibrils, which are superluminal in coordinating the two reactive ends, see Figure 5.



Each of photon A and B may take a different path, e.g. interferometer arms, or entanglement experiment, but the assembly is still connected, hence entanglement. Each reactive end responds to the external constraints on all the other reactive ends.

Figure 5: Qualitative explanation of two-photon entanglement. The photons are predicted to originate from a Pauli pair of electrons – these electrons are bonded in a transphasic interaction and hence their emitted photons also have that interaction. Consequently the four reactive ends of the two photons are linked by fibrils, even as they move further apart. As a result the behaviours of the photons are coupled: hence entanglement.

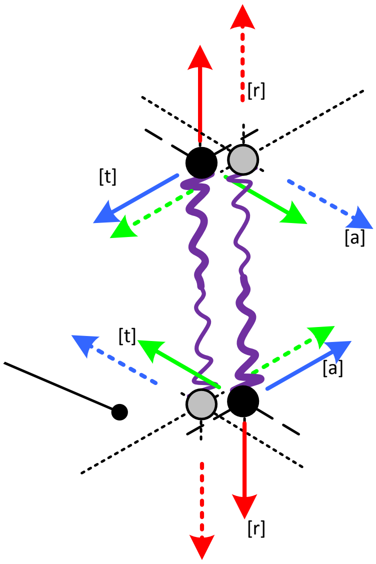
The theory provides that the fibrils of photons are able to be stretched to any length [15]. However massy particles like electrons are predicted to be unable to be stretched in the same way, because their span is required to be inversely proportional to their energy hence to frequency. This is consistent with the empirical evidence that photon entanglement can be accomplished over macroscopic distances, but electron entanglement is difficult to achieve and has only been demonstrated at small scales, e.g. in quantum dots and molecular arrangements [24-26].

Einstein-Podolsky-Rosen paradox

The Cordus principle of synchronisation of emissions also explains the Einstein-Podolsky-Rosen paradox [3]. In this thought-experiment the variable of one particle, e.g. the spin of an electron, is measured and then that of a second particle, e.g. the spin of the other electron in the orbital, is always found to be in the opposite state. This is considered a paradox because it is unclear how the two particles interacted to communicate their states to each other to contrive such a result. Other interpretations are that the uncertainty principle has been violated, or that the QM wave-function does not give the complete description of reality.

The explanation from the Cordus theory is that the two electrons orientate themselves alongside each other spatially, and then synchronise their emissions to be transphasic. This creates a coherent state whereby two reactive ends (from different electrons) are co-located but emit their discrete forces out of phase with each other (180^{o} timing). Other work in the theory, as applied to atomic nuclear structures, shows that cisphasic and transphasic interactions confer stability on the assembly [23], and this principle has been used to explain the nuclides (H to Ne) [27].

The same principle is proposed for the case of an electron pair. The Cordus theory predicts two frequency states in an 180^{o} interaction: ci- and trans-phasic. These correspond to QM 'spin'. Thus the spins of a coherent assembly of two electrons, i.e. an entangled pair, are required by the Cordus theory to be opposed, see Figure 6. So if the spin of one such particule is measured, that of the other will always be in the opposite state, as EPR observed. The fact that the electrons are sharing the orbital means that they have pre-arranged to be in a transphasic interaction even before the Observer makes the measurement. So to the Observer the outcome of the experiment looks like an act of non-physical contrivance by the particles, but this is merely an artefact of the particles being in a transphasic coherent state to start with.



The reactive ends of the two electrons look after each other's location in a complementary way

Figure 6: Proposed structure of the Pauli pair, whereby two electrons are bonded with a transphasic interaction.

The Cordus theory also explains why electrons exist in Pauli pairs, and hence why atomic orbitals comprise pairs of electrons rather than some other quantity. There are also several other phenomena that the Cordus theory explains in terms of physical realism, where QM has no explanation. Thus the spatial alignment of this Cordus structure gives a natural explanation for spin and polarisation, something that QM cannot provide. Likewise the process for how the electron emits or absorbs a photon is explained by the Cordus theory [15], which is otherwise difficult to explain. Another difficult spin problem for QM is why the neutrino species should have specific spin – and indeed why they move at the speed of light. The Cordus theory provides a physical explanation for this [18] [28].

5 Discussion

5.1 Outcomes

This paper makes several original contributions. First, it critiques the inequality methods on logical grounds. The finding is that those methods are flawed because they take premises that are weak or circular. Consequently we rebut the common finding that hidden variable theories are non-viable, and instead assert that the inequalities only show that hidden-variables are non-viable within the overly limiting 0-D point framework of quantum mechanics. Hence the findings of the inequalities are consequences of the 0-D construct, and their conclusions are limited to QM. The inequality methods do not exclude hidden variable theories or any other theory where particules have substructure. This is a far-reaching conclusion given the extent that the inequality method has been used to justify QM and exclude HV theories. We do agree that it is necessary to exclude *local* hidden-variable theories on logical grounds, whether or not that is actually what the inequalities prove.

Second, we have shown that the C&R proof is capable of the opposite interpretation to that proposed by its authors. The premises imposed by C&R mean that the proof is applicable to QM, but not to physical theories generally. Instead of showing the purported superiority of QM over hidden variable theories, it appears to show that QM is conceptually curtailed and cannot be extended. This is because QM is intrinsically founded on the premises of 0-D points and probability distributions. Such premises do not permit reconstruction of any deeper mechanics, whether of the Cordus theory or any other. The implication is that quantum mechanics may not be the way forward to the next physics.

Third, we rebutted the inequalities by demonstrating that a non-local hidden-variable solution is conceivable and explains those phenomena that are otherwise peculiar to quantum mechanics: superposition, entanglement, and wave-particle duality. Importantly, this theory is not an extension of quantum mechanics. The new theory is applicable to a variety of different phenomena, hence does not suffer from the historical limitations whereby hidden-variable theories had narrow scope of application. The ability of this theory to explain superposition and entanglement is especially relevant because it conceptually explains the indeterminism whereby 'measurements generate random outcomes'.

Fourth, the Cordus theory provides a coherent set of explanations for a variety of phenomena that are difficult –or impossible- for QM to explain. These are not detailed here as they are covered elsewhere. Results are available for multiple phenomena, including recovery of the basic optical laws (Snell's law, Brewster's angle, etc.) [10], matter and antimatter species differentiation [14], annihilation process including the differences between ortho- and para-positronium [29], pair production [30], motion and selective spin of the neutrino species [18] [28], decay of nucleons [17] [31], process of photon absorption [15], process of photon emission [32], pair production [30], strong interaction [16], explanation of the nuclides (H to Ne)[23] [27], weak interaction [17], beta decay processes [18], decay processes in general [31] [33], asymmetrical baryogenesis and leptogenesis [34], time-dilation [35], entropy [36], and the horizon question [28]. All parts of the theory are logically consistent with each other, as opposed to being disparate theories aggregated together. This has further implications for the development of fundamental physics as it shows that NLHV theories do have explanatory power.

5.2 Implications

This work has philosophical implications for realism and its relevance for fundamental physics. Quantum mechanics posits that fundamental particles comprise 0-D points with intrinsic variables. The QM perspective therefore denies that these variables exist objectively, and the corollary is that QM rejects physical realism. The consequence is that QM is unable to explain phenomena in natural terms, but this is offset by the remarkable quantitative success of the theory. In contrast the present Cordus theory offers a specific structure for the sub-particle, and suggests deeper mechanisms based on physical realism for phenomena such as superposition and entanglement. Thus physical realism is supported in the new theory. This is a significant outcome because realism has largely been dismissed as irrelevant due to the ascendancy of quantum theory. Consequently it seems more hopeful than it has been in many years that it could be possible to create a theory of fundamental physics based on physical realism. Achieving this would create a new physics different to the existing theories of quantum mechanics and string theory. This longer-term objective is worth pursuing for the potential to provide a fresh perspective on how fundamental physics might be integrated with general relativity. The development of a mathematical formalism is desirable to take this forward, and the current work provides a candidate conceptual foundation for this.

A second implication is that the theory proposed here conceptually subsumes quantum mechanics, since the 0-D point of QM can be interpreted as a spatial and temporal simplification of a deeper structure at the sub-particle level. It is possible, at least conceptually, that the wave function of QM is a stochastic approximation of a deeper, faster, and more deterministic behaviour at the sub-particle level. The quantitative mechanics of QM are preserved, though only applicable at the scale at which fundamental particles may be approximated as 0-D points. If so, this implies that quantum mechanics is not a scale-invariant theory. This is consistent with the observation that QM entanglement and superposition do not occur in the macroscopic world in which we live.

5.3 Limitations and future work

There are several limitations to this work. First, it is unknown whether other better solutions than the Cordus theory might exist. Nonetheless it is sufficient for falsifying the inequality method to show that *one* such solution exists.

A second limitation is that the work relied on logical rebuttal and provenance of a conceptual solution, but this was not proved mathematically. Hence the explanations offered for entanglement were qualitative, and the correlations of the Bell-test angles have not been shown qualitatively. Specific future work could be the development of a mathematical formalism to represent the Cordus concepts and apply them to the Bell-test entanglement. Achieving this would provide a stronger case for the viability of the theory.

Third, we have rebutted the assertion of the inequalities that fundamental particles cannot have internal structure, but we have not positively proved that the inner structures operate on the principle of physical realism. We have merely demonstrated that a specific internal geometry permits a viable solution. There is still a possibility that a better theory of physics may exist where particles have hidden variables that are *not* geometrically based (as here), but are instead based on some other principle. Related to that, we have proposed structures at the sub-particle level, but implied that there may exist still deeper structures. These we have not defined. For example, we have not identified the structure nor mechanisms of the proposed discrete forces. It would appear from our work that fundamental physics has further deeper levels of phenomena. This could be an opportunity as much as a limitation, since there is reason to believe from some philosophical perspectives that physical realism could have deeper and deeper shells of causality. In contrast all causality stops at the particle level for quantum theory.

6 Conclusion

The first part of this work rebutted the inequality approach, and showed how the C&R proof is undermined by its own premises. The second part falsified the inequalities generally by showing that it is possible to conceive of a theory of physics that explains superposition and entanglement, without using quantum theory. This is significant because these phenomena have historically been considered to be only explainable with quantum mechanics. In this new theory particles are proposed to have a specific internal structure, hence this is a type of non-local hidden-variable theory. These structures provide the underpinning causality for behaviours including spin, polarisation, charge, frequency, matter-antimatter species differentiation, superposition, and entanglement. Consequently the inequalities do not preclude the possibility that a theory based on physical realism might apply at the next deeper level of fundamental physics.

Author Contributions
All authors contributed to the creation of the underlying concept, development of the ideas, and editing of the paper.

Conflict of interest statement
The authors declare that there are no financial conflicts of interest regarding this work. The research was conducted without personal financial benefit from any third party funding body, nor did any such body influence the execution of the work.

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