Theoretical article

A physical explanation for particle spin

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Abstract

CONTEXT - The spin of a particle is physically manifest in multiple phenomena. For quantum mechanics (QM), spin is an intrinsic property of a point particle, but an ontological explanation is lacking. In this paper we propose a physical explanation for spin at the sub-particle level, using a non-local hidden-variable (NLHV) theory. **APPROACH** - Mechanisms for spin were inferred from the Cordus NLHV theory, specifically from theorised structures at the sub-particle level. **RESULTS** – Physical geometry of the particle can explain spin phenomena: polarisation, Pauli exclusion principle (Einstein-Podolsky-Rosen paradox), excited states, and selective spin of neutrino species. A quantitative derivation is provided for electron spin g-factor g = 2, and a qualitative explanation for the anomalous component. **IMPLICATIONS** - NLHV theory offers a candidate route to new physics at the sub-particle level. This also implies philosophically that physical realism may apply to physics at the deeper level below QM. **ORIGINALITY** – The electron g-factor has been derived using sub-particle structures in NLHV theory, without using quantum theory. This is significant as the g-factor is otherwise considered uniquely predicted by QM. Explanations are provided for spin phenomena in terms of physical sub-structures to the particle.

Keywords: non-local hidden-variable theory; Cordus; g factor; fundamental physics; spin

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1 Introduction

The spin of a particle is a key concept for particle physics, and is physically manifest in multiple phenomena such as Pauli pairs, photon polarisation, superconductivity, selective spin of neutrino species, and electron spin g-factor. Despite spin having physical effects, it has no ontological explanation. Quantum mechanics (QM) instead treats it as an intrinsic parameter. This paper offers a physical explanation for spin using non-local hidden-variable (NLHV) theory, specifically the variant called the Cordus theory. It is shown that, under the assumptions of this theory, spin parameters arise naturally as properties of the physical structures at the sub-particle level. This is then used to provide physically explanations of the Pauli Exclusion Principle and the selective spin of neutrino species. The electron g-factor is derived and it is shown quantitatively that g=2 for this NLHV theory.

2 Context: Orbital and spin angular momentum

Background

In classical mechanics angular momentum is rotation of a body around an axis. The classical regime gives way to the Fermi-Dirac probability distribution when the separation between particles is much smaller than the de Broglie wavelength of the particles.

In particle physics there are two types of angular momentum, orbital and spin. The sum of orbital angular momentum and spin is the total angular momentum for the particle. The total is conserved, though momentum can be transferred between the orbital and spin components, hence spin–orbit interaction.

The *orbital* angular momentum is generally believed to involve a particle moving in a circular locus, such as an electron moving round the nucleus, or two quarks spinning around each other. It is quantised, as opposed to being a continuous variable, and takes on integer values. The *spin* angular momentum (or simply 'spin') is analogous to a quantised rotation of the particle, e.g. the electron, about its own axis. Quantum mechanics disfavours an interpretation of rotation, and instead considers spin to be an intrinsic property. QM also rejects the idea that spin could arise from smaller internal particles rotating around a spin axis, as in a bag or plum-pudding model. The confirmatory evidence appears in the electron spin g-factor. At the particle level the quantum spin is measured with respect to a direction set by the observer, and the outcomes are represented by probabilities of finding the particle with spin in that direction (projection). Under QM the particle has no physical orientation either.

Spin is a vector with a total value and a direction. The fermions take spin values of odd half-integer increments (1/2, 3/2, 5/2, etc.). The spin of the electron, proton, and neutron is 1/2 and this applies to the leptons and quarks generally. These particles are subject to the Pauli Exclusion principle, that two co-located particles are unable to be in the same spin state and instead take different spin directions, e.g. +1/2 and -1/2 to achieve this. In contrast bosons have integer spin. These include the photon, mesons (quark plus antiquark), and Higgs boson. These bosons follow Bose-Einstein statistics, i.e. there is no interaction between multiple particles, and they can co-locate. It also applies to some atoms, hence condensed states of 2He2 in superfluidity, and electron Cooper-pairs in superconductivity. Atomic nuclei with even mass number have integer spin, and odd have ½ spin.

These attributes of particles are well quantified but no deeper explanation is available.

Application

Spin is an important property that is often used in entanglement experiments [1-4] and interferometry [5]. It is also a key feature in the further development of quantum theory, e.g. the Higgs mechanism and muon properties. The table of nuclides also shows that spin is key to understanding the properties of the nucleus [6]. Other phenomena where spin is important are annihilation [7-9], including of muons [10], proton size anomaly [11], and aspects of cosmology such as leptogenesis [12]. Spin is also practically important in optical tweezers [13].

Ontological challenges
There are several conceptual problems with spin. The first is explaining how spin arises at the fundamental level, why particles have the values they do, and what underpins the Pauli Exclusion principle and Bose-Einstein behaviour. For example, QM does not offer any deeper explanation of why spin numbers prevent fermions from co-locating.

A second problem is the lack of explanation for why the *type of assembly of particles* should affect the spin. For example, individual electrons are fermions, whereas a pair of electrons (Cooper pair) is a boson. Likewise, why are nuclides with odd total of nucleons fermions, while those with even totals are bosons?

Third, there is no satisfactory explanation why *multiple* 2He2 nuclei and Cooper-pairs do not also physically co-locate like the photons. They do not contract to a singularity. Given that all are bosons, one expects a consistent behaviour from the same spin property. A related question is why should spin be exclusively 1/2 for elementary fermions, yet merely predominately 1 for bosons? What is the basis of this differentiation?

A fourth issue is that, though quantised, the spin of a particle is nonetheless functionally linked to classical angular momentum, as shown in the empirical Einstein–de Haas effect (an electric current in a coil causes a magnet to rotate), and the complementary Barnett effect (an object becomes magnetised when spun). Why is this?

Contrasting perspectives
It is undisputed that the spin property can be *formalised* within quantum mechanics. However QM does not provide an *ontological* explanation of how these behaviours arise. Attempts to provide physical interpretation have been undertaken from the outset of quantum theory, e.g. by Dirac [14], but spin remains resistant to such description within QM. It is generally accepted that there is no explanation, that the properties are merely intrinsic, that QM is complete as a theory as it is, e.g. [15].

It is understandable that QM would construct spin this way. After all QM is premised on particles being zero-dimensional points, hence internal structures are disallowed. Nonetheless, from a NLHV perspective there ought in principle be an underlying mechanics or sub-structure to the particle, but in practice such explanations have been elusive. While the simpler classes of NLHV theory have been excluded by the Bell-type inequalities [16-18], it has not been possible to rule them all out [19]. Hence it is not impossible that a NLHV theory may provide a solution, but in practice it has been difficult to find workable variants, and hence this branch of physics has become obscure. Historically the main NLHV theory was the de Broglie-Bohm [20, 21]. There has continued to be interest therein [22-24], but it has not yet progressed to a comprehensive theory of physics. More recently the Cordus variant of NLHV theory [25] has been shown to explain multiple physical phenomena.

Brief summary of the Cordus theory
The Cordus theory [25] postulates the existence of specific physical structures at the sub-particle level, and functional behaviours thereof. Philosophically the theory is premised on physical realism - that observable phenomena have underlying physical mechanisms [26]. Design principles were used to construct the theory, hence the features are not arbitrary

conjectures [25]. The theory predicts that particles have internal structures and externally emitted discrete forces [25, 26]. See Figure 1 for the predicted structure of the electron, and Figure 2 for the photon. The particle is proposed to have an *inner structure* comprising two *reactive ends*, which are a small finite distance apart (span), and each behave like a particle in their interaction with the external environment, when they are energised. The reactive ends are proposed to emit discrete forces, which react with external fields, matter, and photons. A *fibril* joins the reactive ends and provides instantaneous connectivity and synchronicity between the two reactive ends. It is a persistent and dynamic structure but does not interact with matter. There is also an *external structure* whereby the reactive ends periodically energise (at the de Broglie frequency), and in doing so emit *discrete forces* that have components in three orthogonal directions. These discrete forces are connected in a flux tube and emitted into the external environment. The whole is sometimes termed a *particle* where it is necessary to differentiate from the point particle of QM. For further details of the internal structures see [26, 27].

One of the implications is that particles are linear structures of finite length – they have size. They also have orientation determined by discrete force emission. It is also not relevant to think of the particle as a solid volume of material, or a spinning ball of charge. This is especially relevant later when considering the electron spin g-factor.

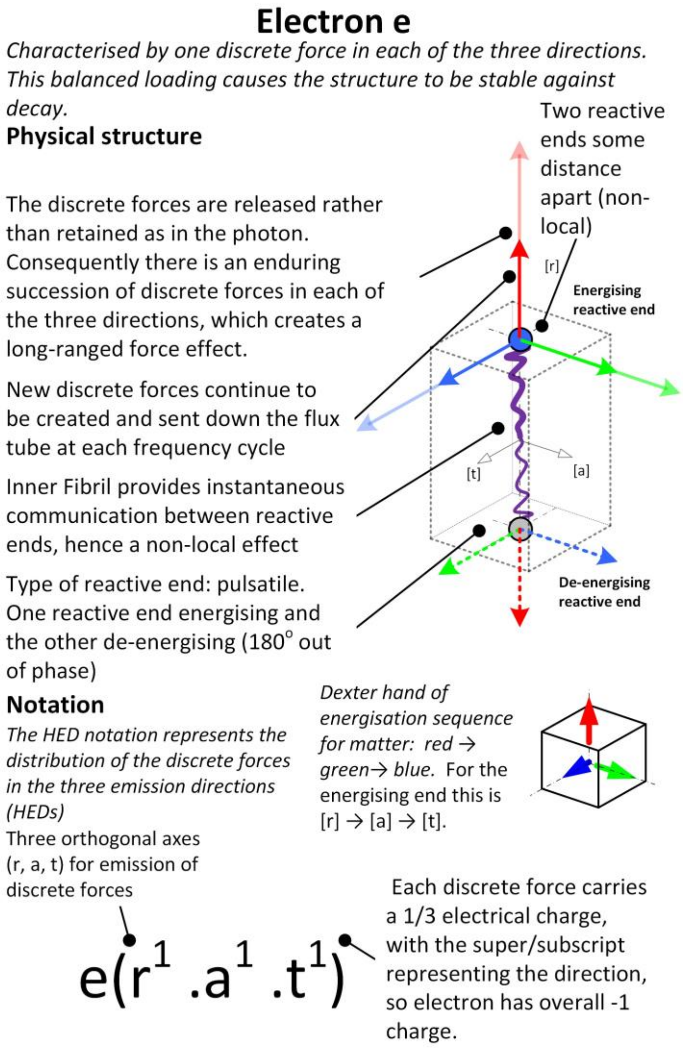

Figure 1: The Cordus design for the electron, showing the reactive ends, fibril, and discrete force emissions. Adapted from [28].

In this theory, an important difference between the electron and photon is the nature of the emissions. The electron - and all massy particles – are proposed to emit discrete forces and release them into the external environment to contribute to a fabric of discrete forces. The reactive ends are energised in turn. In contrast the photon is proposed to shunt its discrete force in and out of the fabric, without releasing them. Also both reactive ends are simultaneously active, in opposite directions of transmission. This is important later when considering the Pauli principle.

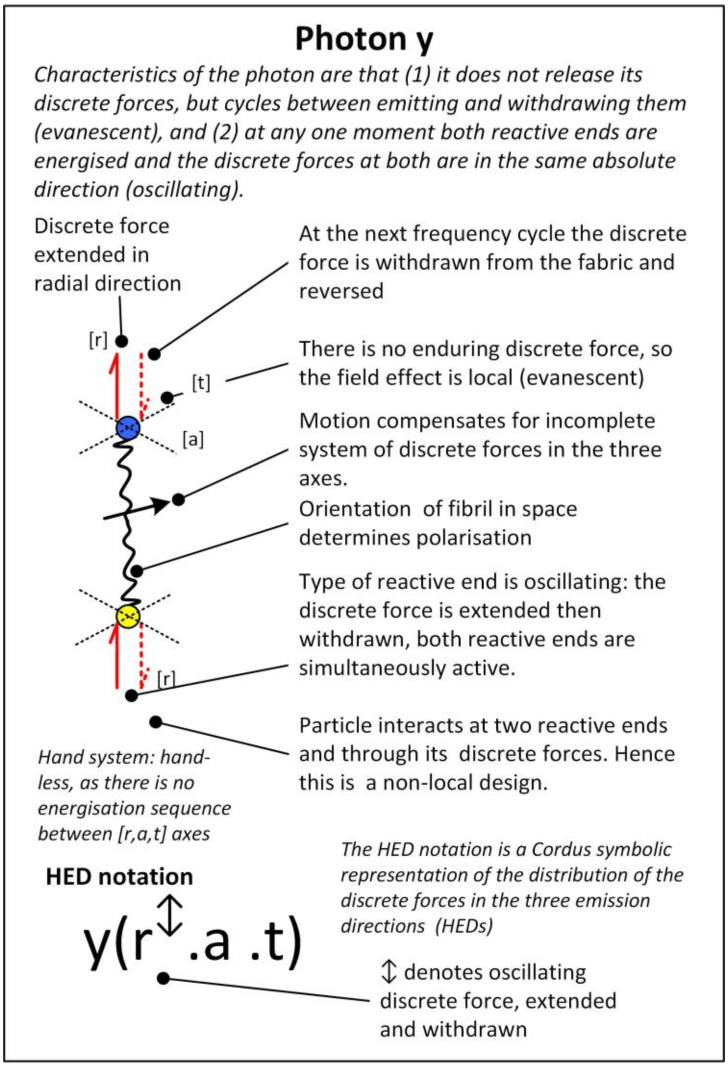

Figure 2: Proposed internal structure of the photon, showing the dual-energisation of the reactive ends, and the shunting arrangement of the discrete forces. Adapted from [29].

The theory has been used to explain the following phenomena:

- wave-particle duality in the double slit device [25],
- derivation of optical laws from a particle perspective [25],
- explanation of the decay processes and prediction of a deeper unified decay model [30, 31],
- explanation for the selective spin characteristics of neutrinos whereby the direction of spin is correlated with the matter-antimatter species [30],
- explanation for the annihilation process including a conceptual explanation of the difference between otho- and para-positronium decay rates (ortho and para refer to spin combinations of the bound electron and anti-electron/positron) [32],
- provision of a mechanics for pair production [33] and likewise photon emission [27, 34],
- structure of atomic nuclei and explanation of stability for nuclides H to Ne [35, 36],
- prediction of a mechanism for asymmetrical baryogenesis in terms of a newly predicted decay path for remanufacture of the antielectron to the proton [37],
- origin of entropy [38],
- a theory for time as an emergent property of matter [39],

- nature of the vacuum and the cosmological horizon [40],
- origin of the finite speed of light [41],
- quantitative derivation of the relativistic Doppler and the Lorentz factor [42].

3 Method

The purpose of the current work was to prospect for deeper explanations for spin from the Cordus NLHV theory. The present work extends the theory for superposition and entanglement [26].

We used this theory to infer candidate physical structures for spin. We did not find it necessary to change the fundamentals of the theory, though we did identify specific dimensions that were tacit in the original theory. We show that spin may be understood as a geometric attribute of the internal structure of a Cordus particle.

The resulting theory provides a description of spin that is quantised and does not involve orbits. We found that the theory predicts additional spin properties beyond those recognised by QM. The distinction between these properties is lost when one reduces the structure to a point particle, hence the QM perspective is able to be recovered.

We tested the theory for logical congruence against known phenomena of Pauli exclusion, excited states, and selective spin of neutrino species. For the later see also prior work [30]. Explanations were found for these effects, and did not require new assumptions in conflict with the original premises.

We then applied the theory to determine the electron spin g-factor, and quantitatively recovered the Dirac g-factor. We explored the anomalous dipole moment, and found a qualitative explanation for it, but a quantitative derivation was elusive at this time.

4 Results: A proposed physical basis for spin

4.1 Orientation angles for spin

Since Cordus particles have span, they consequently have angular orientation relative to a reference frame. Their frequency behaviour means they also have a phase property [43]. We propose these as the basis for spin.

The key spin variables in this theory are the orientation angles of the fibril, and the energisation phase. If the fibril is orientated with the axis of measurement, then there is only one variable, which is the energisation phase, see the electron model above. However in the more general situation the number of dimensions (variables) required to define a Cordus particle is three linear dimensions [x, y, z] for location of a reactive end, one for the length of the span (related to type and energy of the particle), up to three polarisation angles for the orientation of the discrete forces, one composite variable to denote the discrete force content (this differentiates the type of particle) [27], another for the degree of overloading of discrete forces, and one phase variable to indicate which reactive end is energising. The matter/antimatter hand, which is identified as the hand of energisation sequence, requires another variable [32, 44].

Depending on how they are counted, that gives a total of 11 independent variables to fully define a Cordus particle. Not all these dimensions are simple numbers: some like the number and charge of discrete forces are sets, though this is not apparent in the case of the electron but instead becomes evident in say the neutron [31]. The photon has a still simpler discrete force structure and does not need all these variables.

The dimensions of particularly interest for spin are those of orientation. In this theory the spatial orientation of one particle relative to another is defined by several angles: the phase of energisation θ, and three orientation angles for the fibril and system of discrete forces A_1, A_2, A_3, see Figure 3 and text following.

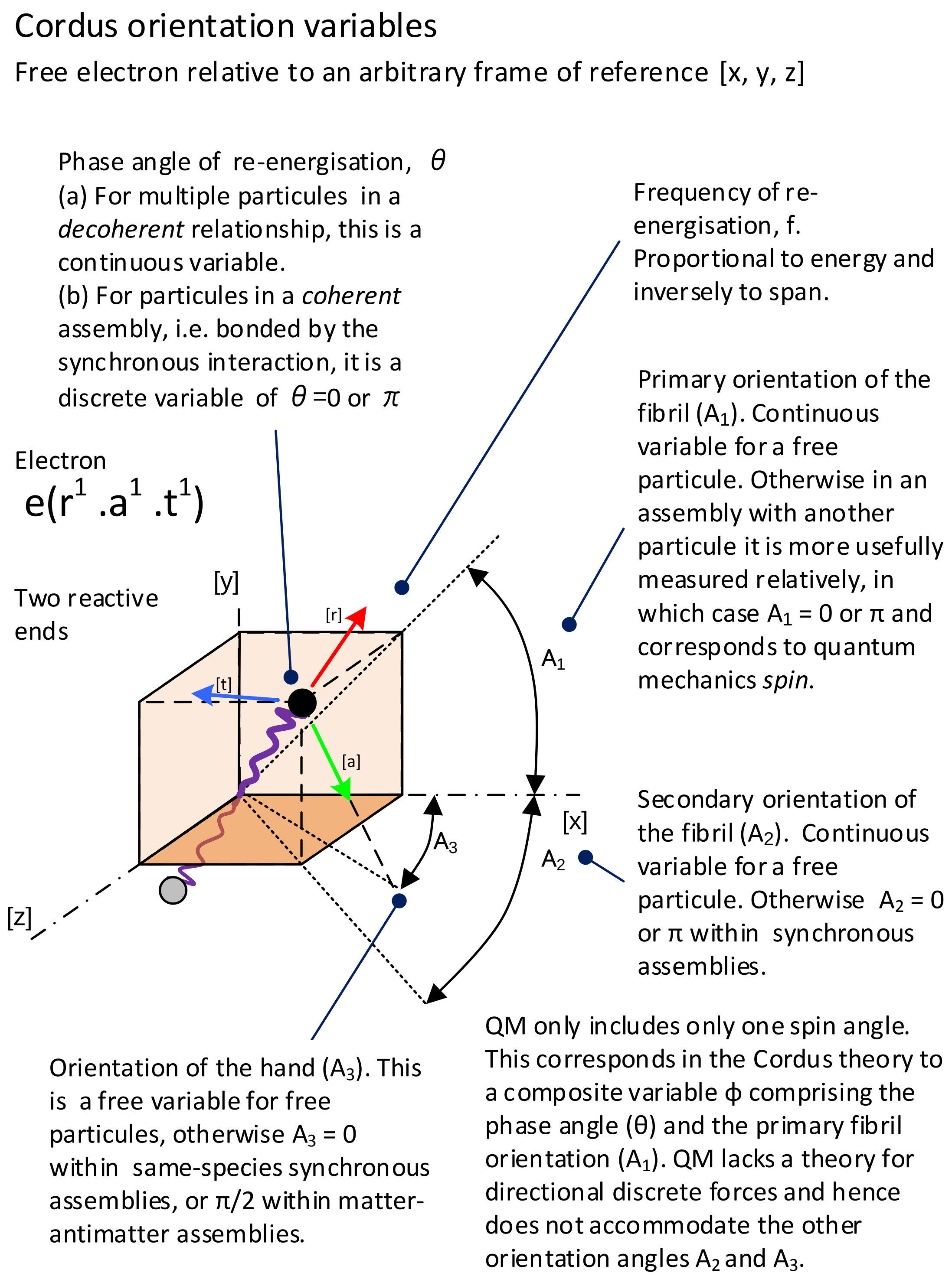

Figure 3: Definition of Cordus orientation variables that define spin.

4.2 Predicted sub-types of spin

We identify several different *types of spin* within the Cordus theory. It is proposed that not all these are manifest in every situation, and some are predicted only to be evident at a finer scale. Several of these spin variables are naturally inaccessible to representation in quantum theory because it assumes particles are 0-D points.

Number of Reactive ends (E)

The number of reactive ends in the particle, which is two rather than say three, indicates the *energisation frequency model* of the particle. For the Cordus theory E=2 for a single particle. For QM, and any theory built on a 0-D point construct, the number of reactive ends is E=1. For electromagnetic wave theory, where a dipole construct is sometimes used, E=2.

Intra-Energisation state (s)

This indicates the energisation state of the reactive end at the moment under examination. The *s* variable denotes the energisation state of a reactive end at the moment in question. For matter particles like the electron, one reactive end is energising s(1) while the other is de-energising s(0), i.e. the two reactive ends are 180^o out of phase, hence a s(1,0) structure. The reactive ends thus pulse with discrete force emissions. There is no emission of discrete forces at the de-energised state. At each ½ frequency cycle the state of any one reactive end changes.

For the photon, both reactive ends are simultaneously active. At any one moment, one reactive end is emitting a discrete force and the other is retracting its emission, s(+½ ,-½). The photon oscillates its emissions. The reactive ends are simultaneously active, though in different directions. At the next ½ frequency cycle the state of the reactive ends changes.

Nuclides with even numbers of nucleons and symmetrical polymers emit discrete forces simultaneously in all directions, though from different locations in the polymer [35]. At a sufficient coarse scale of observation, where the span of the polymer is considered to be zero, this would appear to be a particle with simultaneous emissions in all directions, i.e. s(1,1). This, we propose, is the basis of the bosonic attribute of nuclides with even numbers of nucleons.

Fibril orientation angle (A_{1-3})

This measure of spin refers to the orientation of the fibril of a single particle, relative to another particle or frame of reference. The necessary parameters are two angles A_1 and A_2 describing the orientation of the span, and a third angle A_3 for the alignment of the [a] axis. These apply to massy particles and the photon. They correspond to polarisation angles for the photon in electromagnetic wave theory.

Inter Phase angle (ϑ) – cis and transphasic

There is a relative phase angle θ of energisation between two neighbouring particles. If the particles are in a *coherent* relationship, which requires synchronisation of discrete forces and a common frequency of the energisation ω, then the only options are θ =0 (*cisphasic*) or θ = π (*transphasic*) energisation [32, 43]. In the more general case of a *discoherent* relationship then there are no restrictions on θ. In this way the Cordus theory provides a means to differentiation coherent and discoherent (discord) states of matter. This is difficult to explain with other theories.

Discrete force pairs

The difference in orientation of matter-antimatter discrete force pairs is interpreted as a form of spin at a deeper level within the particle. The Cordus notation for these is $x_{\underline{1}}^{1}$ and $x_{1}^{\underline{1}}$ [30, 32]. This concept is not needed for the present discussion, but is included for completeness as it is important in the proposed Cordus processes for decay and the weak interaction [31], photon emission [34] and pair production [33]. It is also relevant in the solution for asymmetrical baryogenesis [37].

Angular momentum (M)

This spin refers to angular momentum. The interpretation is of a free Cordus particle rotating about an axis. For an individual particle or decoherent assemblies of particles this spin may be a continuous value. However in coherent systems it is quantised due to the synchronicity of the interactions between the particles [43]. Hence it is proposed that the quantised nature of spin arises from the coherent assembly of particles, specifically from their mutual alignment of emission directions.

Handed motion (H)

Spin hand refers to the direction of the angular momentum relative to the direction of motion, and may be clockwise or anticlockwise. This is a geometrically simple concept but it has potentially profound implications because it explains the selective spin characteristics of the neutrino matter-antimatter species, see below and [30]. Hence it is possible with this theory to explain why neutrinos spin the one way, and anti-neutrinos the other. This has otherwise not been explained with conventional QM.

Having proposed the origins of spin variables at the sub-particle level, we next apply these principles to explain several phenomena.

5 Applications of Cordus theory to quantum phenomena

5.1 Empirical measurement of spin

The Cordus theory proposes that measured spin corresponds to phase and angular orientation of the fibril of the particle.

This is consistent with how spin is measured empirically. In a coherent light source the photons are produced with a certain orientation, and this occurs either at emission or by subsequent filtering using polarisers to exclude non-compliant orientations. Also the component of electric field, hence component of spin, may be measured in an axis set by the observer. These light sources produce many photons and the probabilities measured by quantum mechanics represent these components and the underlying stochastic variability. A number of photons are sacrificed for measurement purposes, and used to infer the properties of the wider ensemble. Hence also, a decoherent light source produces photons with uncontrolled orientations, and this is represented in quantum mechanics as indeterminate spin. The Cordus theory is consistent with these results, but explains them as arising from the geometric properties of the particle. Thus it is proposed that the aligned molecules within polarising filters really do selectively obstruct photons that have orientation that is non-compliant with the filter.

5.2 Coherence and decoherence

The Cordus theory proposes that coherence arises when adjacent particles synchronise the phase of emission of their discrete forces.

Within the Cordus explanation for spin there is a differentiation between coherent and decoherent assemblies of particles [43]. This is not a distinction explainable with quantum theory. The Cordus theory proposes that the formation of coherence between two or more matter particles requires their acceptance of a common (or harmonic) *frequency*, and a common *phase* of emissions. This is because the bonding is via the synchronous interaction (strong force), which as the name implies requires synchronous emission of discrete forces [43]. This fixes the frequency ω of the particle to a common or harmonic value.

The synchronous interaction also makes the three orientation angles A_1, A_2 and A_3 into local constants, so they are no longer variables. The only remaining variable is the phase angle θ, which in the coherent case is either cisphasic ($\theta=0$) or transphasic ($\theta=\pi$). Consequently for coherent assemblies of matter, both frequency and phase are no longer variables for an individual particle but are instead group properties. We propose this as the physical mechanism underpinning superfluidity, superconductivity, and Bose-Einstein condensates (see below).

Multiple particles that are in *decoherent* assembly have their own independent parameters for all these variables. Such assemblies are predicted to interact via the electro-magneto-gravitational (EMG) forces instead of the synchronous force.

As this shows, physically meaningful definitions of spin are provided in this NLHV design. However there are more spin variables here than provided in quantum theory. This can be explained as follows. QM assumes that all particles are in a coherent assembly state, which means that all the angles of polarisation are fixed, and the frequency too. Consequently the only spin variable left in a coherent body is the phase θ, which can only take two values (since the particle has two reactive ends). This explains why spin is discrete in quantum mechanics. QM does not extend to describe ensembles of decoherent particles, which is what the other Cordus variables are used for.

5.3 Pauli Exclusion Principle

The Cordus theory proposes that pairs of electrons can share a common space by arranging to have transphasic (opposite phase) inter-particle relationships.

This theory may be applied to understand the interaction between electron Pauli pairs in orbitals. The two electrons in an orbital are known to have opposite spin when measured, hence the Einstein-Podolsky-Rosen paradox. 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.

The Cordus theory explains the situation as follows. The two electrons share locations for reactive ends but in opposite (transphasic) re-energisation phase, see Figure 4. This transphasic interaction protects the emission directions of the assembly, and is thus energetically favourable for the individual participants. This also explains why there are *only two* electrons in each orbital, not more, hence the Pauli Exclusion Principle. Hence the two electrons are always found to be in complementary states when measured. The fact that the electrons are sharing the orbital means that they have pre-arranged with each other (and the nucleus) to be in this complementary state even before the Observer started the interrogation, so to the Observer the outcome of the experiment looks like an act of contrivance by the particles. However that is merely an artefact of observation.

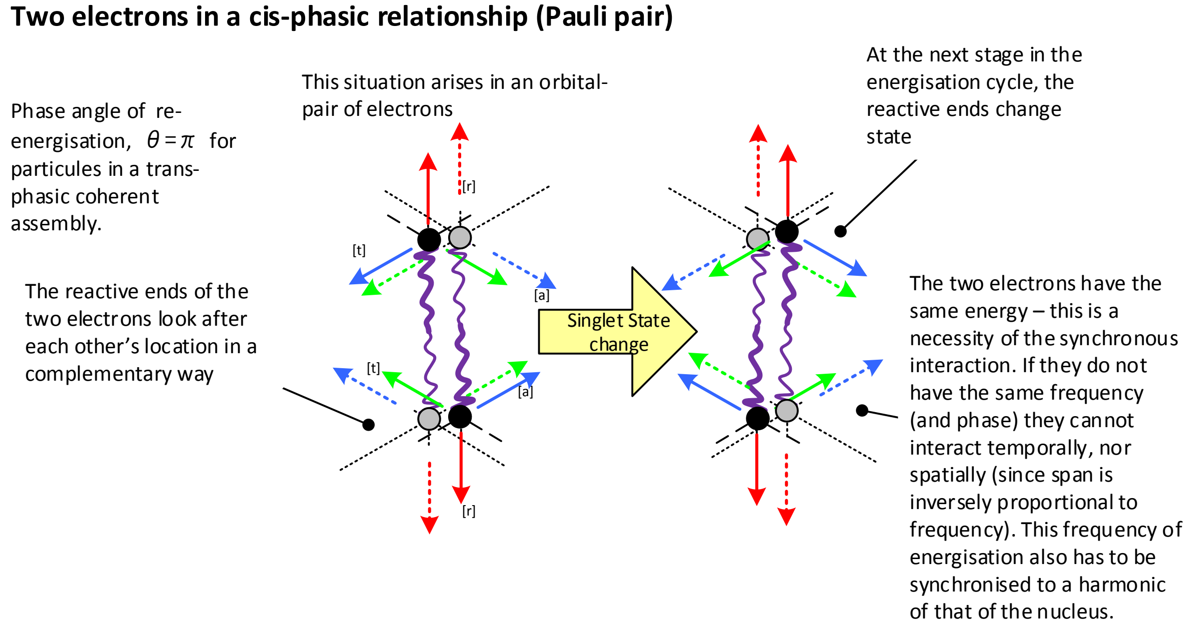

Figure 4: The Cordus explanation for the spin arrangements for a Pauli electron pair.

Note that it is not the *absolute* orientation of the particle that is proposed to be important, but the *relative* orientation between the two particles. In a coherent system, the two particles can *only* be either in phase with each other or out of phase, hence only two spin states are possible for Pauli pairs. In the more general case where two electrons are *not* in coherence with each other, there are infinitely many orientations that the fibril may take. This is proposed as the reason why the Pauli exclusion principle only applies in special situations like orbitals.

In this context the Cordus particle concept can also be extended to larger assemblies such as atomic nuclei [45]**.** It is able to explain why each of the nuclides H to Ne are stable, unstable, or non-existent [36]. It does this by proposing that the protons and neutrons are also linear structure like the electron, and that these form closed chains or *nuclear polymers* [35]. The polymers are stabilised by bridge neutrons, which accommodates the empirical observation that heavier elements need more neutrons for stability.

5.4 Excited states and photon emission

The Cordus theory proposes that excited states comprise one electron in a set adopting a higher harmonic frequency, while still retaining synchronous interactions with the basal particle(s).

The behaviour of excited states can also be understood in terms of this Cordus theory. In an excited state one of the electrons (B) in a Pauli pair absorbs energy. In the Cordus explanation, this energy causes the B electron to increase its frequency and decrease its span. It therefore moves into partial temporal and spatial de-synchronisation with electron

A (which remains in the ground state). B can persist in this state by finding a harmonic frequency with which to interact with A, a type of spin gearing. However the interaction is also, via A, with the rest of the nucleus. The nucleus has a large resistance to changing its spin attributes, due to its large mass.

Electron B may transfer some energy into electron A and the nucleus, as part of the process of negotiating a mutually acceptable set of harmonic frequencies. Or it may emit the energy as a photon. Emission is also covered by this theory [27, 34]. This is a precise interaction and any excess energy above that needed for the relevant frequencies is a hindrance, and is discarded. Thus the orbital system takes only certain discrete energy states. Hence the quantum nature of discrete energy levels can also be qualitatively explained using this NLHV theory. This negotiation process takes frequency cycles, hence time, and thus the transitions are not instantaneous.

The relationship between electrons A and B thereby changes from the direct 1:1 synchronicity of the ↑↓ state (this notation refers to the discrete forces, see Figure 1), to one where electron B is at a higher harmonic frequency. B is then trapped in this state. Subsequently an external perturbation means that B is no longer in an energetically sustainable position. It is expected that B will more easily revert back to the ground state when it and A are momentarily in a cisphasic relationship ↑↑ (or ↓↓). For it to make the transition back to the transphasic state ↑↓ it needs to change its frequency to that of A, and move into the opposite phase. The Cordus theory separately identifies mechanisms whereby a particle can skip half a frequency cycle by emitting a photon [27]. If this photon also carries away the energy difference, then the spin adjustment is complete, and the intersystem crossing occurs. Hence this is a phosphorescence emission.

5.5 Selective spin of neutrino species

This theory proposes that the physical mechanism for the matter-antimatter species differentiation is the handedness of the energisation sequence of the discrete forces [44]. Given three axes, there are only two such sequences, which are dexter and sinister (right and left). Expansion of this concept has been used to explain annihilation [32], pair production [33], and asymmetrical baryogenesis [37]. When coupled with the concept of spin described above, the theory also explains the unique spin characteristics of the neutrino species [30]. The physical evidence is that the neutrino always spins one way relative to its motion (left handed), and the antineutrino the other (right handed).

The proposed mechanism is that the neutrino species have incomplete discrete force emission and hence must recruit discrete forces from the fabric. This results in reactive translational and rotary motions. The direction of spin motion is determined by the energisation sequence, and this is also the matter-antimatter species differentiation, see Figures 5 and 6.

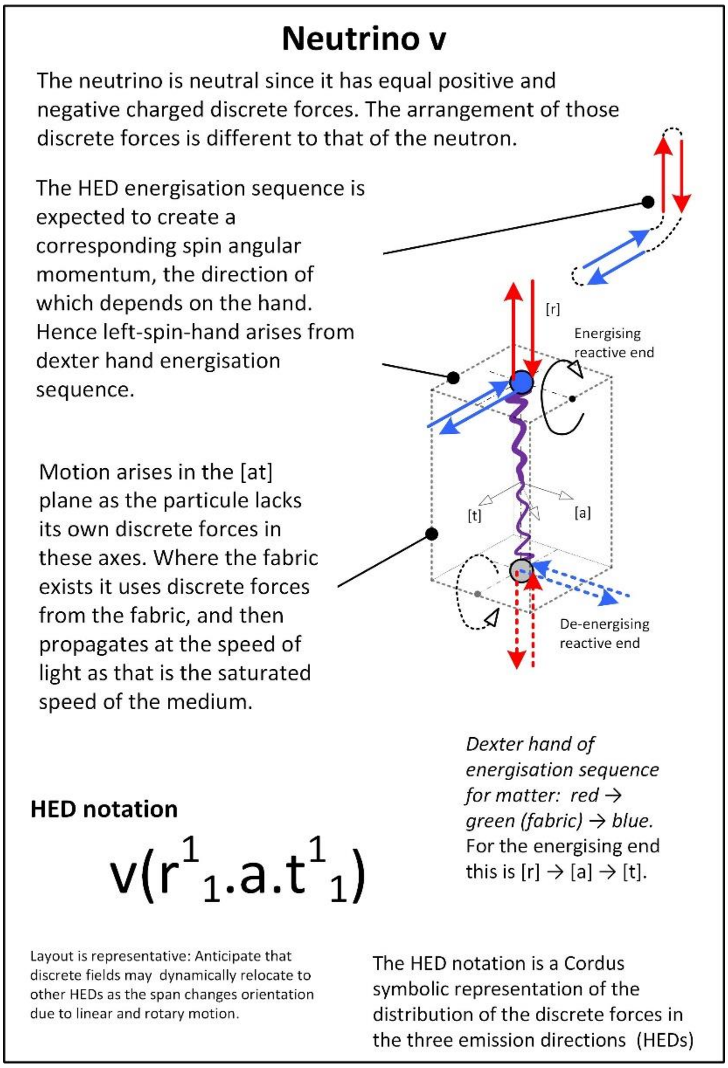

Figure 5: Proposed structure of the neutrino, including internal structure and external discrete force structure. The imbalance of the discrete forces results in linear and spin motions. The latter is uniquely determined by the energisation sequence, hence matter-antimatter species. Image adapted with permission from [30].

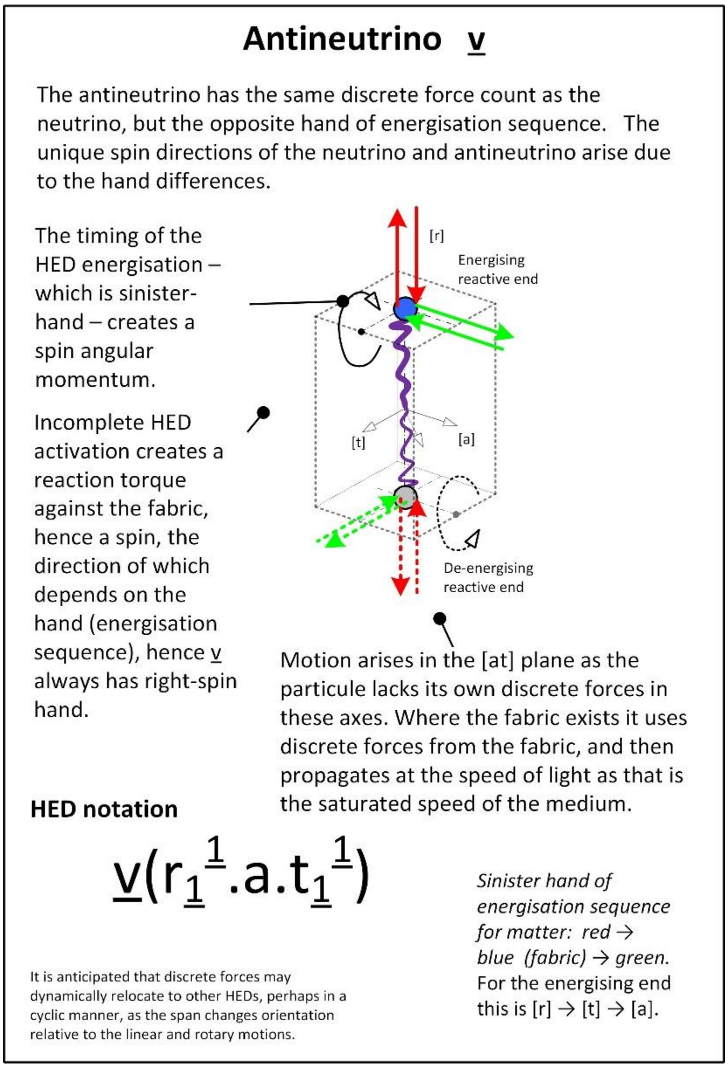

Figure 6: Proposed structure of the antineutrino, including internal structure and external discrete force structure. This particle spins in the opposite direction to the neutrino, because of the difference in energisation sequence of the discrete forces. Image adapted with permission from [30].

Up to here the explanations for spin phenomena have been quantitative. We now demonstrate that the theory quantitatively recovers the principle component of the electron g-factor.

6 Electron spin g-factor

Thompson's plum-pudding model of the atom proposed electrons in a matrix of positive charge, making up a solid ball. That concept of solidity was disproved by Rutherford [46] in the gold-foil experiments. This led to the modern idea of quantum mechanics, with a nucleus and electrons in orbitals. Even though quantum mechanics treats particles as 0D points, there is still an acceptance that particles occupy space stochastically such that macroscopic matter has volume. For example the proton has an empirically known charge radius. It is invariably assumed that such particles occupy the whole of their volume, even if non-uniformly and not continuously in time. This assumption is important in what follows.

Dirac explored the assumption that the electron had its charge on an outer conductive spherical surface [47]. If particles like the electron were solid spheres, or comprised sub-particles in a *solid spherical* matrix, and if the same sub-particles contributed fractionally to both charge and mass, then it would be expected that the moments of charge and mass would be the same.

Empirical evidence shows this not to be the case, and suggests that the internal sub-charges would need to be distributed differently to the sub-masses. More specifically, the *g-factor* represents the constant of proportionality between the magnetic dipole moment μ_s which measures spin of a charge, relative to the spin angular momentum S which measures the moment distribution of mass. The Dirac electron spin g-factor is approximately twice the spin, more accurately 2.00231930436153. That this is about 2 rather than 1 is evidence that the charge of the particle is distributed very differently to its mass. This is considered one of the key characteristics of QM, since no other theory of physics has been able to explain why g=2. There is a further triumph for QM, since the anomalous magnetic dipole moment (the discrepancy from 2) can be calculated to high accuracy by quantum electrodynamics [48].

Explanation of electron g-factor with Cordus particle theory

In what follows we show that the new theory is able to derive g=2. In the Cordus theory the electrostatic field strength of an electric charge is determined by the *signed sum of discrete forces* emitted by that charge. The theory predicts, in contrast, that *mass* is determined by the *total number of discrete forces,* irrespective of their charge. Hence some particles (e.g. the neutron) emit *charge-neutral* pairs of discrete forces that contribute to mass but not to charge [31]. This is an important difference. In neutral particles, such as the neutron, it is proposed that both positive and negative discrete forces are emitted so the net electrostatic field strength is zero, but there are still discrete forces contributing to the mass and gravitational effect. In other particles, like the proton, both effects exist: there is a net external charge and a neutral part. These are the overt and implicit (or covert) parts respectively [49]. Thus the implicit discrete forces contribute to mass, and hence to spin angular momentum. In this theory, mass is also determined by the energisation frequency, whereas charge is not [50]. Hence higher frequencies cause more discrete forces to be emitted in unit time, hence greater mass.

Hence the Cordus theory predicts different mechanisms for the electric field and mass. In contrast the classical perspective is of a spherical solid body with a radial dispersion of both charge and gravitational field. For the electron, in the Cordus theory, the discrete forces are identified as a complete set of one emission in each of the three axes, hence e= [r^1, a^1, t^1] without covert discrete forces [33]. This sums to one unit of charge and one unit of mass. We show that the electron g-factor for this arrangement is 2.

Start by noting that the electron spin g-factor is a constant included in the Dirac particle equation:

$$\mu_e = g_e . \frac{\mu_B}{\bar{h}} S_e \tag{1}$$

where μ_e is the electron magnetic moment which measures the distribution of charge, g_e is the electron spin g-factor, μ_B is the Bohr magneton, e is the electron charge, $\bar{h}$ is the reduced Planck constant, and S_e is the spin angular momentum which measures the distribution of mass.

Identify the Bohr magneton, where m_e is the electron mass:

$$\mu_B = \frac{e\hbar}{2m_e} \tag{2}$$

Hence by substitution and rearrangement:

$$g_e = 2\frac{\mu_e/e}{S_e/m_e} \tag{3}$$

The term μ_e/e is the *moment of charge per unit charge*, and S_e/m_e is the *moment of mass per unit of mass*.

In the Cordus theory the mass and charge interactions occur at the reactive ends, since the discrete forces provide the underlying mechanisms of causality. Hence it is *at the ends of the span* that the discrete forces act. Furthermore, the frequency of emission for the charge and the mass is the same, since both are serviced by the underlying energisation process: the electrostatic force is proposed to be from the linear action of the discrete forces, and the mass & gravitation from the torsional action of the same complex of discrete forces. Both effects originate at the reactive ends. Thus the Cordus theory predicts that the moment arm for charge is the same as that for mass, hence:

$$\mu_e/e = S_e/m_e \tag{4}$$

The above moment arm considerations are important. In contrast the classical perspective is that the mass is contained uniformly *inside* a spherical volume whereas the charge is distributed on the *surface* of that volume, hence different moment arms for the two effects.

Substituting Eqn 5 into Eqn 4 gives the electron spin g-factor per the Cordus NLHV theory:

$$g_e = 2 \tag{5}$$

This recovers the Dirac electron spin g-factor. This is novel as the derivation is from the Cordus particle theory. This finding disconfirms the classical idea of a particle being a simple spherical solid body. The finding is consistent with QM but independent thereof and derived from a NLHV basis.

Anomalous magnetic dipole moment

The empirical evidence is that g_e is slightly more than 2, i.e. that the moment of charge is larger than the moment of mass, g = 2.00231930436153. This small difference is called the anomalous magnetic dipole moment. It is explained by quantum electrodynamics as an interaction between the electron and one or more virtual photons. QED is able to calculate g_e to high precision, which is one of the great successes of the standard model.

The Cordus theory explains the anomalous magnetic dipole moment as an interaction between the electron and the fabric. The fabric in this theory comprises the volume of space containing the discrete forces emitted by all the particles in the observable universe [40, 41]. The energisation of a reactive end creates and emits a new discrete force into this fabric. There will exist random events when a discrete force in the fabric happens to be co-located and aligned (cis) or anti-aligned (trans) with this new emission, and the response of the particle is slightly asymmetrical.

Where the discrete forces of the electron and the fabric are *aligned* the effect is to momentarily retard the emission of the discrete force, i.e. postpone the effect of the charge into the future. This fractionally reduces the strength of the charge in the present moment. For the case where the discrete forces are *anti-aligned,* the combination creates the structure of a photon [27]. This new photon has a brief existence in the fabric. The brevity is due to the two discrete forces, one from the fabric and the other from the electron, being members of separate flux tubes with spatially diverging commitments. Consequently the created photon is merely a temporary random alignment. This is similar to the QM concept of 'virtual photon'. The temporary photon moves a small distance in its brief existence, and then separates into its constituent discrete forces. However we propose that it can occasionally be absorbed by a third particle, such as a passing neutrino. Hence the anti-aligned pairing fractionally neutralises charge, hence *reduces* effective charge while preserving charge moment. The effect is less pronounced for mass, because of the greater statistical improbability of three discrete forces from the fabric having the necessary coincidence. Inspection of Eqn 4 shows that the effect of these two asymmetries is to increase the g factor above 2. This is not inconsistent with the Schwinger radiative correction [48].

Likewise other fortuitous alignments of discrete forces may mimic the discrete force structure of other particles, such as electron-antielectron, or quark-antiquark pairs, and thereby create virtual particles of these types too. These will also make a small contribution to fractionally decreasing the effect of charge. However these other particles have more complex discrete force structures, and hence the probability of these structures being correctly presented by the randomness in the fabric are smaller. Hence heavier virtual particles will be rarer and make a smaller overall contribution. This is similar to the QED prediction of a secondary contribution by hadronic vacuum polarisation [51].

Muon g-factor

The g factor effect is not proportional to mass, within a family of particles, because the spin angular momentum scales proportionally with increased mass, e.g. for the muon $S_\mu \propto m_\mu$. Nonetheless the muon g factor is not identical to that of the electron, but is instead slightly greater with $g_\mu = 2.0023318414$. Our explanation is that the higher energisation frequency of the muon causes it to emit discrete forces more often, and hence a greater exposure to forming a virtual photon with a discrete force from the fabric. These interactions decrease the effective charge and increase the g factor. In contrast the standard model imputes this to greater access to heavier virtual particles.

The implication is that the fabric density affects the production of virtual photons. The Cordus theory predicts that the production of virtual photons will be proportional to the fabric density, and the alignment thereof with the particle. We make the falsifiable prediction that the anomalous magnetic dipole moment is not universally constant. Instead we predict g_e will be greater in situations of higher fabric density (e.g. regions of higher gravitational field strength or denser galaxies or relativistic velocities), and should display a correlation with orientation (e.g. spin relative to alignment towards charged objects or large bodies of coherent matter). Since the fabric density is temporally and spatially variable in the universe, this further implies that the anomalous magnetic dipole moment changes with epoch and location in the universe. An interesting future research question is whether the anomalous moment might be used to determine the absolute value of the local fabric density.

It makes sense that the production process of virtual photons should depend on the fine structure constant α. This is because α is interpreted in this theory as 'a measure of the transmission efficacy of the fabric, i.e. it determines the relationship between the electric constant of the vacuum fabric, and the speed of propagation c through the fabric' [27]. Hence α relates to electrical forces and propagation of fields, which includes electron bonding.

7 Discussion

7.1 Commentary

Starting from first principles of geometry, we have shown that physical structures at the sub-particle level can explain multiple spin phenomena including polarisation, features of coherent-decoherent assemblies, Pauli exclusion principle (Einstein-Podolsky-Rosen paradox), excited states, and selective spin of neutrino species. We finished by recovering the electron spin g-factor $g \approx 2$, and explaining why the anomalous magnetic dipole moment and muon g-factor are greater.

7.2 Implications

We have shown that phenomena considered to be uniquely quantum may be explained by theories other than QM. The conventional interpretation is that the electron g-factor precludes the possibility of fundamental particles having internal structure. Hence QM asserts that spin truly is an intrinsic property. The present work falsifies this by deriving the g-factor using NLHV structures without recourse to quantum theory.

We have achieved this by departing from the conventional assumption that any hidden variable solution would comprise smaller particles rotating about a central mass, somewhat like planets orbiting the sun, the defunct plum-pudding model, or the extant bag models of nuclear structure. Such designs would indeed not explain the g-factor. However there is no need to limit the design of a NLHV solution to an orbital arrangement. By conceptualising a radically different arrangement, we have shown that the g-factor may be recovered.

The g-factor result is more than an interesting curiosity, because it does not stand alone. The same theory has been applied to many other phenomena. It derives from first principles the laws of optical reflection and refraction [25], explains the stability of the atomic nucleus [35, 36], derives the Lorentz factor [42], explains asymmetrical baryogenesis [37]. Other parts of the work address time [39], entropy [38], and the strong force (synchronous interaction) [43]. The theory is logically consistent across all these explanations. This strengthens the case for a new physics based on hidden variables.

The wider implication is that the next deeper level of physics would be based on particles having sub-structures. While the possibility of a non-point structure has been considered from the outset of quantum theory [52], up to now the difficulty has being devising an alternative structure. This is especially as the Bell type inequality tests precluded many types of internal structure [16]. However the specific structure predicted by the Cordus theory is not precluded by the Bell tests [26]. The new theory implies that there is a deeper determinism to particle behaviour, which is approximated by the stochastic representation of quantum mechanics. As shown in the above references, a unification between features of particle behaviour and general relativity is conceptually feasible at this deeper level. This is another attractive feature of the theory.

7.3 Limitations

The limitation of the theory is the lack of a mathematical formalism. In this regard quantum mechanics is much superior. We derived the basic form of the electron g-factor using a mathematical approach, but not the anomalous part. We have yet to find a form of mathematics to represent the Cordus theory – this is an open problem. The number of geometric variables in the Cordus particle is broadly consistent with string/M theory, though the theories come at the problem with different approaches. Possibly this hints at a correspondence, in which case some of the string theories might be formulated to create a mathematical representation of the Cordus particle structure.

7.4 Implications for future research

We have only addressed the first of the questions identified at the outset: how does spin arise at the fundamental level? The other questions remain: Why are nuclides with odd total of nucleons fermions, while those with even totals are bosons? Why do some bosons (photons) stack, whereas other bosons like 2He2 nuclei do not co-locate? Why only ½ spin for elementary fermions and predominately 1 for bosons? What is the physical mechanism for the Einstein–de Haas and Barnett effects?

8 Conclusions

This work make several original conceptual contributions. We propose that the spin property arises from the internal structure of particles, and this is new. We have predicted what those structures are, and how they relate to spin. Consequently the work provides a physical explanation for spin, which is has not been achieved before.

The new spin theory provides a conceptual explanation for a variety of observed spin behaviours. Existing quantum based theories already provide quantitative formalisms in some cases, but an ontological explanation has been lacking.

Another contribution is the advancement of the non-local hidden-variable branch of physics. By addressing the spin behaviours and deriving the electron g-factor, the comprehensiveness of the Cordus theory has been enlarged. The theory provides a single coherent framework that explains spin (this paper), photon absorption & emission [27, 34], matter/antimatter & annihilation [32, 44], nuclide structures and stability (to at least Ne) [35, 36], strong interaction [43], weak interaction [31], decay sequences [30, 49, 53], asymmetrical genesis (baryogenesis and leptogenesis) [33, 37], time dilation [39, 42], aspects of cosmology [40, 41], entropy [38], and wave-particle duality [25, 26]. This is original as it provides wider coverage than other NLHV theories.

This theory explains multiple spin phenomena that are held to be uniquely quantum effects: Pauli electron pairs, excited states, and the electron spin g-factor g≈2. An explanation, albeit qualitative, is also offered for the anomalous component. Explaining these using a theory of physics other than QM is original.

Another accomplishment is offering an explanation of the selective spin characteristics of the neutrino species. This has not been explained with other theories.

In summary the work demonstrates that a physical basis can be conceived for spin, and that the electron g-factor can be explained by NLHV theory. Consequently we reject as unnecessary simplification the QM premise that particles are 0D points and particle properties merely intrinsic, and instead we propose the principle of physical realism applies. We suggest the idea that particles do have internal structure is a promising concept for advancing fundamental physics.

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Contribution statement

All authors contributed to the general development of the theory. DP lead the development of the specific explanations provided here. DP wrote the first draft of the paper and all authors contributed to its finalisation.

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