Circumventing Bell's theorem? Design of a non-local hidden-variable model with physical substructures

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Abstract

The purpose of this paper was to look for non-local designs of particles. We show that the Bell-type theorems are not proof against a hidden variable solution, by presenting such a model complete with the first level of internal functional structures. A design method was used to infer the internal structures that would be necessary to explain the observed phenomena of entanglement. The result is a novel model called the cordus particule, which is proposed to have two reactive ends that are separated in space. The model proposes the internal structures and provides mechanisms showing how the external behaviour arises from those structures. A mechanism is given for superluminal entanglement. The model predicts outcomes from Bell-type tests that are consistent with empirical results. This shows that it is conceptually possible to create hidden-variable solutions that are based on physical sub-structures. We suggest that the better interpretation of entanglement and the Bell-type theorems is that both local realism and the zero-dimensional point construct are false. The cordus model produces a new concept for the mechanism for locality and the extents thereof, and implies the need to abandon strict locality and local realism, at least at the deeper level. Nonetheless an approximate retention of both locality and realism is provided. The results suggest it is worthwhile questioning the established ideas of physics regarding the composition of particules, and we particularly identify the zero-dimensional point construct as ripe for revision.

Keywords: Bell's theorem; entanglement; locality; local realism; point; hidden variable; non-local hidden-variable theory

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1 Introduction

Physics is based on the construct that particles are zero-dimensional (0-D) points. Thus fundamental particles (photon, electron, etc.) are modelled as 0-D points, and atoms are believed to be assemblies of points. Using the 0-D point model has proved to be very successful, as quantum mechanics (QM) has shown. Yet there are problems, particularly the lack of physically descriptive explanations for the mechanisms that QM predicts. One of the

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fundamental questions is what, if anything, may be the internal structure of matter.

The specific case under examination here is the incongruence that arises from attempting to reconcile entanglement with locality. Bell's theorem [1] places firm constraints on the interpretation of these effects. In particular, it precludes *local* hidden-variable solutions.

Quantum mechanics is undoubtedly successful, and together with general relativity forms the dominant conceptual framework of physics. However, while the *quantitative success* of those theories is unquestioned, the *conceptual integration* between them is lacking. This suggests that they may not be the whole reality: there is a logical place for a deeper mechanics that subsumes them both. Furthermore, the *descriptive explanatory power* of quantum mechanics is poor, and this is another reason to think that there might be a deeper mechanics. As Marco stated,

> *'A possible way out from these problems [non-locality and the inability of QM to scale to macroscopic levels] would be if QM represents a statistical approximation of an unknown deterministic theory.'* [2]

If there is a deeper theory, it is unknown. Bell's theorem rules out local hidden-variable models, and several other classes of solutions are excluded on other grounds, so it is not obvious where such a radically novel solution might be found. Nor is has it been possible to fix QM by incremental improvements, at least not yet. So questions of locality, the structure of matter, and the mechanisms for entanglement are still wide open.

The purpose of this paper is to explore the *non-local* solutions. We probe the reasons for the irrelevance of Bell's theorem to this class of solutions. We inspect the properties of a non-local design, with a particular focus on the cordus conjecture. The results are interpreted as disfavouring the 0-D point premise, and producing a new concept for the mechanism for locality and the extents thereof.

2 The Principle of Locality and its failure

2.1 Bell's theorem

Bell's theorem [1] predicts that local hidden-variable theories cannot explain superluminal entanglement (non-local causality).

The principle of *locality* is that the behaviour of an object is only affected by its immediate surroundings, not by distant objects or events elsewhere. Hence also *local realism*: that the properties of an object pre-exist before the object is observed, and independent of observation. Scientists generally accept the premise of local realism: it seems consistent with how the physical world is expected to operate. They also generally expect locality.

Bell's theorem sets these against each other by implying that only one perspective can be correct: either superluminal effects or local hidden-variables do not exist. The many actual experimental results are generally interpreted as supporting non-locality behaviour in quantum mechanics. There is the slim possibility of doubt as not all loopholes for 'mutual rapport' (Bell's term) between particles have been closed. The effect is commonly demonstrated with photons.

Local realism is a premise of science, and if it does not exist, then how do we make sense of the physical world? But entanglement does seem to occur. Moreover, it occurs consistently with how quantum mechanics quantifies the situation, which seems to validate QM. But Bell's theorem says that only one can be correct, so we are generally forced to conclude that local realism does not exist. However that fractures the logical consistency of our mental model for reality: How can it not exist? What is the mechanism for non-locality and entanglement? Those are difficult questions.

Bell's original statement was that a 'grossly non-local structure ... is characteristic ... of any ... theory which reproduces exactly the quantum mechanical predictions' [1]. In other words, entanglement effects require particles to have a non-local structure. The current way of expressing this is that no theory using local hidden variables will be able to reproduce the entanglement and all the other predictions of quantum mechanics.

The theorem has subsequently been interpreted differently, semantics in this area being problematic, but Bell's original intent was a direct response to the EPR criticism [3] and was clearly intended to show that faster-than-light cause-and-effect (hence superluminal causality) could not be explained by any set of additional variables [4].

The terminology has changed over the decades, but the current logic goes something like this: only superluminal entanglement or local realism exists, not both > entanglement is observed > thus particles are not influenced solely by the values of the fields or effects at that particular point, but rather influenced by remote events > therefore local realism is false > thus particles must have a non-local structure > the mechanism for this influence is unknown (that is not a major obstacle) > whatever the mechanism, it cannot involve initially encoding the two entangled particles with some 'hidden variable' before they were separated (the EPR paradox [3]) > neither can any hidden variable theory that relies on locality (even one not yet discovered) predict the outcome probabilities from the empirical tests (which QM can) > therefore no theory of local hidden variables can ever be a viable model.

Locality refers to the surroundings, and thus Bell's theorem excludes designs where particles are only influenced by the values of the fields or effects *at that particular point*. Thus it excludes *local* hidden variables.

This is almost invariably interpreted as proving that particles can have no internal structure either. Quantum mechanics and the 0-D point construct reinforce each other. Quantum mechanics has impressive success at predicting the outcomes of entanglement, and for many physicists it is convincing evidence that QM (and its point construct) is a correct descriptor of reality. However this need not be strictly true, because Bell's theorem only precludes *local* hidden-variable solutions, not all types.

Superdeterminism

There are some alternative approaches. One way this has been attempted is via superdeterminism, in which everything, including the choices made by the experimenter, are determined beforehand by some deeper determinism. Thus there is no free-will either. However there has been no viable theory of *local* hidden variables emerge from this line of thought. It is not even certain that one is feasible, though it is not impossible.

2.2 Non-local theories

More generally, Bell's theorem does not exclude hidden-variable theories of the *non-local* kind (NLHV). This is not contentious, though the difficulty is creating such a theory.

Trajectory models

A prominent non-local theory, and perhaps the only one of any significance, is the de Broglie-Bohm pilot wave theory [5-7] which proposes that the wave-function guides the moving particles down trajectories with position and momentum being hidden variables. That particular theory has its own difficulties, particularly of physical interpretation, and is not widely accepted. For a discussion of this model and the related Nelson stochastic model (which also has trajectories for the particles), and the broader context of hidden variables, see [2].

The de Broglie-Bohm theory is broadly consistent with quantum mechanics in its predictions about photon path behaviour and entanglement. However it is a specialist solution for describing trajectory behaviour, and it does not explain as wide a range of effects as QM.

Crypto-nonlocal hidden-variable theories

The subtype of 'crypto-nonlocal' (CN) hidden-variable theories proposes that the entangled particles are independent to each other. As Leggett observed, these are 'relatively plausible on physical grounds' [8]. However his consideration of these theories showed that 'all CN theories are constrained by inequalities which are violated by the quantum-mechanical predictions' (p1469). Thus most of the possible CN theories would appear to be ruled out too. The Leggett inequalities therefore appear to preclude a specific class of non-local models [9].

Other non-local theories

Much of the search for non-local theories has focussed on adding additional non-local variables in parts, albeit in an ad-hoc manner [10]. However these have not yet proved to be successful [11]. As ideas have developed so they have been shot down on theoretical grounds. For example, Groblacher et al. showed that a broad class of realistic[2] non-local theories was incompatible with empirical results [12]. In similar vein, Gisin offered a proof that there are no deterministic non-local extensions to quantum theory that are covariant [10].[3]

Limited options

So the problem for physics is that entanglement occurs but cannot be explained by quantum mechanics in a physically natural manner. At the same time there is a lack of other theories: *local* hidden variables solutions are proscribed by Bell's theorem, and *non-local* hidden-variable theories are few and have their own rather large problems.

The common coping-mechanism is to relax the need for natural explanations, i.e. accept the weirdness of the QM explanations. In which case quantum mechanics is the best of the available theories. However, it has other problems, e.g. it appears not to scale up to the macroscopic world. That failing, and its lack of natural explanations, suggests that current concepts of 'particle' might not be capturing all that is happening at that level.

If there are non-local models, the solution space in which they hide would seem to be very small, perhaps non-existent.

2.3 Controversy around Bell's theorem

However there is reason to question the validity of the Bell-type exclusions, so the search is not without hope. Mathematical proofs in this area have proved to be contentious, and the conclusions of Groblacher et al. have been vigorously opposed on the grounds that Bell's theorem has been incorrectly interpreted [13, 14].

The original Bell's theorem was relatively straight-forward. It was constructed to show that the EPR proposal that additional variables could restore 'causality and locality' was 'incompatible with the statistical predictions of quantum mechanics' [1]. Much has been made of the quantitative inequalities, but at its core Bell's theorem is a simple prediction that (a) local hidden-variable theories cannot explain superluminal entanglement (non-local causality), whereas (b) quantum mechanics can.

Bell identified *locality* as the 'essential difficulty', and defined the 'requirement of locality' to be 'that the result of a measurement on one system be unaffected by operations on a distant system in which it has interacted in the past'. In this sense locality is the opposite to entanglement. It would seem that Bell's usage of the term 'causality' also referred to 'no action at a distance' [4]. However the theorem has

[2] Those authors used 'realistic' to refer not in the sense of something being representative of real life, but rather to a form of local realism: 'that the results of observations are a consequence of properties carried by physical systems' (p871).
[3] That is 'invariant under a velocity boost that changes the time ordering of events' [Gisin].

subsequently been wrought to other meanings, and has become contentious.

Ambiguous meanings

The issue comes down to one of *meaning*, hence semantics, which are not readily represented in the mathematical treatments. Bell's original purpose was to transform the concepts of EPR into the mathematical domain and analyse them there:

> *'In this note that idea [EPR] will be formulated mathematically and shown to be incompatible with the statistical predictions of quantum mechanics'* [1]

Subsequent efforts have invariably followed the same methodology: mathematical formulation of the problem.

Therein lies the weakness, not with the mathematics but the parsing of concepts into formulae. The primary issues are the meanings assigned to 'locality' and 'realism', and which of these terms, and which definitions thereof, are relevant to Bell's type theorems. Bell did not identify *local realism,*[4] which is a property-and-measurement issue, as the challenge.

However, Laudisa points out that subsequent developments have added realism to the mix, and criticises these as incorrect interpretations [14]. The basis of the criticism follows: Bell's theorem did not require any prior assumptions about realism > subsequent authors have added the premise of realism > the definition of realism used by authors is peculiar > specifically Groblacher's concept of realism [12] implicitly assumes that the physical system has pre-existing properties that (a) do not depend on measurement interactions and (b) pre-determine the outcomes of all possible measurements [14] > that consequently the conclusions derived from such premises are unreliable.

A similar conclusion was reached by de Zela, who argued that Groblacher's concept of realism did not distinguish the contextuality[5] of the measurements, and whether the separations were time- or space-like, and therefore there was a class of hidden-variable models that were still plausible [13].

So the contention is about the meaning assigned to words like 'realism' and 'locality', and which apply in the situation. There is a conceptual fuzziness that underlies the apparently crisp mathematics. One camp includes realism into the Bell-type constraints, and interprets the empirical results as supporting the non-viability of large classes of non-local models. On the other are those who argue that the implicit premises are incorrect and that the interpretation of the results does not exclude hidden-variable models. Either way it is a contentious issue.

[4] Local realism: that the properties of an object pre-exist before the object is observed, and independent of observation.

[5] Contextuality in this case refers to the dependence of the outcome on the 'context in which the measurement takes place or the system is prepared' (de Zela).

If particles really did have hidden internal variables, then we can reasonably expect that line of thinking to deliver a physically descriptive solution. That model would need to propose physical substructures to carry the internal variables,[6] and describe the causal relationships whereby the external evidenced behaviours of the particle are generated by internal mechanisms. None of that has been achieved, not even with the de Broglie-Bohm model, so the current state of affairs is nowhere near a successful outcome. The feasibility of hidden-variable solutions is seriously questionable.

The problem with the hidden-variable approach is that (a) there is no mathematical proof that such a solution is possible in principle, (b) there is no viable physical solution to have emerged from that line of thinking, and (c) the residual solution space is severely limited by Bell-type inequalities and under mathematical siege that would make it still smaller.

The reality is that quantum mechanics is the dominant theory and has escaped unscathed, apart from criticisms about its counterintuitive interpretations. There is an 'extraordinary robustness of quantum theory against any conceivable change' [10].

Opportunity outside the controversy

Given all this, if a non-local model of hidden-variables were to be possible, it would have to be counterintuitive [12]. Therein lies an opportunity: to deliberately look for solutions in unexpected spaces.

Not only to look in unusual places, but perhaps also to look with an unusual method. The method used in the literature is mathematical proof of the existence (non-existence) of certain classes of hidden-variable models. In contrast we propose using design methods to seek physical models.

3 Method

The conceptual design methodology

If we want a counterintuitive solution, then we need lateral-thinking. This is where design thinking is useful, as it can break out of existing mental models and their constraints.[7] The objective in design is to use lateral thinking to create many concepts, subject them to scrutiny and criticism, and take the best candidates forward for further refinement.

If we apply design then we should not be surprised by unorthodox results. Design can be uncomfortable both in process and outcome. The *process* is one of deliberately rejecting the established wisdom, so as to also be free of its cognitive constraints and fixed conceptual framework. The *outcome* can be unusual and even outrageously unorthodox. Radical designs, by

[6] The form required to carry the function.
[7] Applying design-thinking to fundamental physics is already a counterintuitive idea, given that the field is otherwise approached through philosophy and mathematics. Both of those are creative activities, but very different to how the creativity works in design.

their process and outcomes, are assaults on orthodoxy. Such designs cut across existing mental models. However there is no expectation that all or even any designs will prove fit for purpose.

There are potential detriments to the design-method, which we freely acknowledge: there is no guarantee of a solution; the process is subjective; the process is non-repeatable, so application of the same method will generally *not* result in the same solution; a spurious solution may be generated. Furthermore there is not much empirical evidence about internal structure, so the attempt may be premature.

We acknowledge all these difficulties. Nor do we have answers for them all. Nonetheless, that is the type of problem that design is good at solving. Even if design fails to give the correct solution to a problem, it often provides interesting new concepts, and those in turn can sometimes lead to the correct solution.

Where to start?

From a design perspective the many paradoxes in physics are suggestive of an inconsistency in one of the deeper concepts. When designs don't work out, it is often a deeper assumption that is misplaced. Therefore we propose that the way to prospect for a new model of particles is to go questioning at the deeper levels. Of the deeper premises of physics, the idea of 0-D point particles in a 3-D world is a candidate for revision.

The zero-dimensional point premise is a nihilist construct. So that is a potential place to start: it has room for improvement. Unfortunately, reconceptualising the 0-D point premise is not a straightforward task. There is no obvious partial prior conceptual work or empirical evidence on which to build a theory. We know from the Bell-type theorems that the solution space is at best small, and perhaps non-existent. Perhaps for good reason the creation of viable alternative models to the 0-D point model has been historically spectacularly unproductive (bar the de Broglie-Bohm model). When faced with an impasse like this, the design approach is to think laterally rather than continue axially.

The cordus model emerges as a natural artefact from the design process. The process is: accept known empirical behaviours of photons and matter > consider one phenomenon (we started with double-slit behaviour of the photon) > infer the minimal requisite functionality required to sustain the phenomenon under consideration > propose multiple candidate features to carry that functionality > select the fittest and most parsimonious feature > repeat with other phenomena > add more features > check that addition of new features does not compromise the previous functionality (preserve the design intent). The cordus model is an artefact of the design process, and we cannot be sure that a different process would not give a different model, and hence we refer to it as a conjecture.

Thus the method involves logical consideration of how the proposed features might support the empirically-known external behaviour, how the causality might operate (mechanisms), and how the coherence of the concept as a whole develops as different phenomena are considered.

4 Results: cordus conjecture

4.1 Core proposition

The cordus conjecture [15] is a novel theory of particle structure, of the non-local type. A summary of the model is provided below. Elsewhere are described the detailed structure, design logic, progressive expansion of the concept, and the assumptions (the latter in the form of a set of lemmas). It is a designed solution, i.e. a deliberate attempt to conceptually infer the internal structure of particles that would be sufficient to explain the observed external behaviours.[8]

It is important to note that the idea immediately departs from the premise of particles being 0-D points. The construct of 'particle' is not in any way helpful for understanding the present proposition, and we suggest a different term as will be shown.

The starting proposition of the cordus conjecture is the following lemma:

Let every particule have two active ends with a separation between them (lemma zero).

This is a *functional* concept. Exactly what geometry or physical sub-structure creates this cordus functionality is not prescribed at this point. It is necessary to add further assumptions (*lemmas)* to construct a workable model. That construction process is documented elsewhere, and the outcomes follows. The conjecture states that all 'particles', e.g. photons of light, electrons, and the protons in the nucleus of the atom, are not zero-dimensional points, but have a specific internal structure called a 'cordus particule'. It is difficult to represent these new concepts in the terminology of conventional physics, so we have created new words where necessary.

4.2 Proposed internal structure of a particule

The cordus particule consists of two 'reactive ends', which are a small finite distance apart ('span'), and each interact with the external environment. A 'fibril' joins the reactive ends, and is a persistent and dynamic structure but does not interact with matter. The reactive ends are energised (typically in turn) at a frequency. The reactive ends emit one or more force lines (hyperfine fibrils or 'hyff') into space, and when the reactive end is energised it sends a transient force pulse ('hyffon') outwards along the hyff curve. This makes up the field, which is thus also discretised. Various features of the hyff and hyffon carry the electrostatic field, magnetism, and gravitation simultaneously. In this model the photon

[8] By 'external behaviours' we refer to the observed physical phenomena of particles as they interact with the environment around them.

has a single radial hyff which it periodically extends and withdraws. By comparison all massy particules have permanent hyff (including neutral particules like the neutron). Electric charge is carried at 1/3 charge per hyff, so stable particules like the electron are surmised to have three hyff, and these are presumed to be arranged orthogonally, see Figure 1. The hyff around massy particules compete for hyff emission directions (HED), and may synchronise their emissions to access those spaces. Thus there is an element of mutual negotiation, between interacting particules, based on shared geometric timing constraints.

We use the term 'particule' to differentiate this idea from the zero-dimensional 'particle' construct of quantum mechanics. Central to the cordus conjecture is the idea that fundamental particules (electron, photon, etc.) and assemblies thereof, have internal structure.

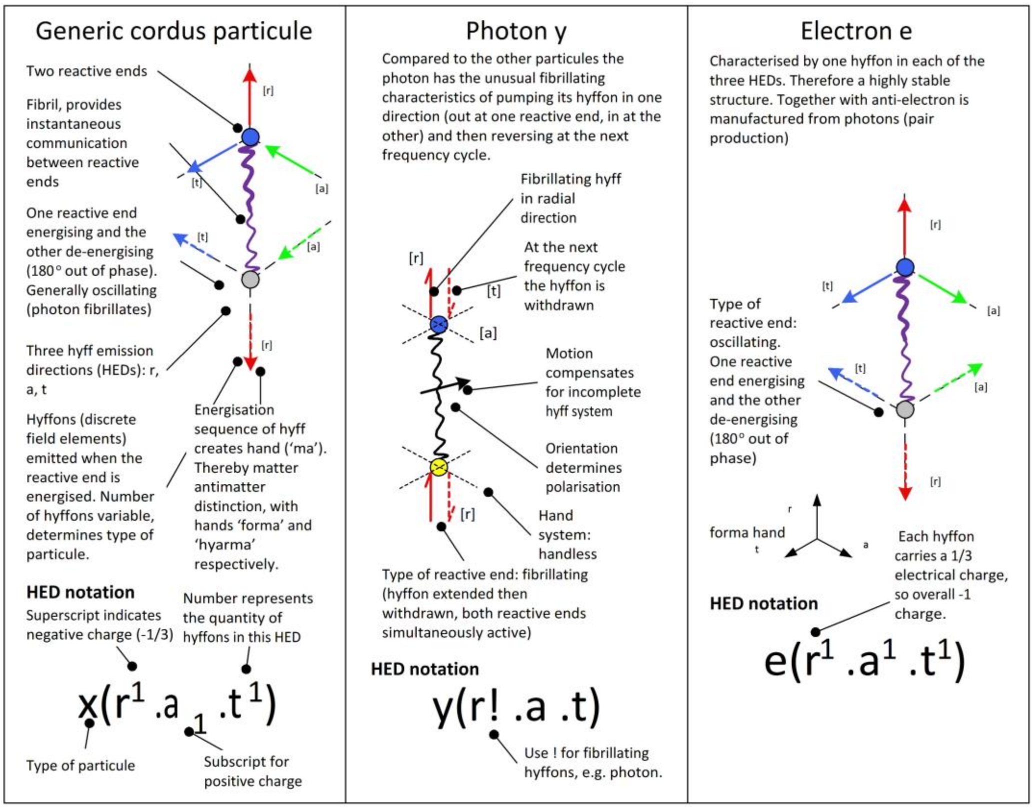

Figure 1: Cordus models for the photon and electron, showing the proposed physical structure and the shorthand notation thereof.

4.3 Mechanism for Entanglement

Applied to entanglement, cordus suggests that the cordi of two photons might may lock onto each other and become synchronised[9] through their discrete field structures (lemma M.1.4 [16]), such that changes to the one

[9] In cordus this is called *complementary frequency state synchronisation* (CoFS) and is also proposed as the mechanism for the strong interaction.

affect the other. The photons are subsequently stretched (lemmas L.1.3 [15] L.5.2 [17]) so that the reactive ends are far apart. What looks like one complete photon at each site is, according to this version of events, two half photons. The fibrils of each are stretched to much greater distances than usual, but still retain their ability to communicate instantly (lemma L.6.15 [17]). Changing one reactive end at one site therefore changes the other and also the second particule, and that change can be immediately observed at the other site, hence entanglement.

Bell-type test

In a typical Bell-type test polarised photons are sent in opposite directions, and at distant locations the polarisation is measured on both beams, with the two measuring instruments (A and B) having variable angular orientation with each other.

In his original paper Bell commented that for a hidden-variable model to give the appropriate statistical predictions for entanglement it would have to include a mechanism for superluminal communication:

> *'there must be a mechanism whereby the setting of one measuring device can influence the reading of another instrument, however remote. Moreover, the signal involved must propagate instantaneously' (p407)[1]*

Cordus interprets polarisation of a photon as the orientation of its field structures to its direction of mutation. Two initially coherent photons will therefore share this orientation in a complementary manner, and retain it as they are stretched to wider span. The polarisation at the location of the one detector will therefore be complementary to that at the other. Cordus therefore predicts that the signal intensity S will depend on the orientation of the detector:

$$\mathbf{S = \sin(\phi)}$$

where ϕ is the angular offset of the detector axis from the polarisation of the photon.

This is indeed what is found empirically, and is also consistent with the prediction of QM, though the results are usually presented in terms of cosine instead.

The empirical results show some scatter, which cordus explains as being due to the practical experiment measuring something slightly different, namely the individual angles of polarisation of multiple photons. In the cordus scheme of things, the photon is stretched over the test, but collapses and therefore appears at only one detector. It is not possible according to the cordus view, to *simultaneously* measure the polarisation of *both* reactive ends of a particule, because the process of measurement collapses the photon or at least interferes with the variable being measured. However the results of multiple photons can be aggregated, *providing* that they are manufactured with the same polarisation: therein lying an opportunity for variability. Some photons collapse at detector A and others at B, and with time enough measurements can be obtained at each to check the correlation.

This cordus explanation is consistent with how the Bell-type tests are actually done: not with individual photons but with many aggregated together, with results showing statistical correlation rather than multiple longitudinal case-studies of individual photons.

We therefore conclude that the cordus conjecture provides a non-local hidden-variable model with predictions that are consistent with empirical results and the predictions of quantum mechanics. We therefore suggest that a valid class of hidden-variable solutions does exist.

Electron pairs

Another application of the cordus principle may be electron pairs in orbitals. The two electrons in an orbital are known to have opposite spin when measured (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 explanation is that each of the electrons have a cordus particule structure with two reactive ends. The two electrons share locations for reactive ends but in opposite re-energisation phase. 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 to be in this complementary state even before the Observer started the interrogation, so to the Observer the outcome of the experiment naturally looks like an act of wilful contrivance by the 'particles'.

But is this cordus idea of internal structure really legitimate: doesn't Bell's theorem explicitly prohibit particles from having internal variables? No: Bell's theorem only prevents *local* hidden-variable solutions. Locality refers to fields and effects *at a point*, and therefore Bell's theorem is only relevant to 0-D point structures. There would appear to be nothing in the current Bell-type inequalities to preclude the proposed cordus model.

5 Discussion

5.1 What has been achieved?

We have created a model of the proposed internal structure of particules. Hence a hidden-variable model. The work is conceptual in nature, but even at this level it predicts entanglement results consistent with empirical results. Specifically a quantitative prediction naturally arises for the results from Bell-type tests with polarised photons. This shows that hidden-variable solutions are possible.

Furthermore we have not simply identified *what* hidden-variables might exist, but have proposed the internal structures and provided mechanisms showing *how* the external behaviour arises from those structures. This shows that it is conceptually possible create hidden-variable solutions that are based on physical sub-structures, i.e. we have produced a tangible physical model too.

Admittedly it is a strange model, but that in itself should not be a disqualifying feature as physics and cosmology have stranger concepts.

Unexpectedly for an unconventional model, it has fitness in several other areas. It offers novel and logically consistent explanations for wave-particle duality, fringes, optical reflection and refraction, superfluidity, strong interaction, coherence, among other phenomena [18]. This shows that it is conceptually possible that a breakthrough in the redefinition of 'particle' could help find solutions to other problems.

Some of its other explanations are rather fanciful such as that for the proposed model of the annihilation process [19], and the sketch of antineutrino based baryogenesis [20]. However if nothing else they show that reconceptualising the nature of 'particle' might access new solution spaces.

It also has some counterintuitive and unorthodox implications, of which the present discussion is limited to locality.

5.2 Implications

The cordus conjecture provides a candidate solution for the problem of particle-structure and locality. If the conjecture were to be correct then there would be implications for fundamental constructs, as follow.

The principle of locality fails

The cordus conjecture assumes that instantaneous communication occurs, hence non-local causality. Cordus proposes that the principle of *locality* fails. (The principle of *locality* is that the behaviour of an object is only affected by its immediate surroundings at that point, not by distant objects or events elsewhere.) Instead it is proposed that the particule is affected by all external fields that exist at its two reactive ends, and by the interaction of its field structures (hyff) with other proximal and remote particules.

We propose a Principle of Wider Locality, that a particule is affected by all the space to which its hyff fields have access, which is in principle the wider universe. Specifically, *a cordus particule is affected by the cumulative effect of the fields in its local surroundings, these being the space to which its hyff have access. Further, that hyff has access to spaces that the physical particule with its reactive ends does not* [16].

Though, perhaps surprisingly, cordus also suggests locality is generally not a bad approximation. This is because the external hyff fields are generally reasonably homogeneous in density, and the particule is usually of small span such that the effects are not generally visible. So 'apparent locality' applies in most situations, especially when only the macroscopic behaviour of the particule is being considered.

So the implication is that locality is generally a sufficiently accurate approximation for practical purposes at the macroscopic level of particules, but not at finer scales or the contrived situation of entangled photons.

Local realism is not supported

Cordus suggests that local realism[10] is more complicated than current models show, and that there are features that cannot be comprehended within the conventional 0-D point paradigm. (

Cordus does accept local realism, to some extent, that properties exist before they are measured. For example, there is proposed to be an underlying determinism in the way that a cordus particule alternates its energy between its two reactive ends. However that mechanism operates so fast that it is generally only measured as a statistic. Furthermore cordus also points out that the act of measurement involves imposing external hyff and thereby affects the system being measured [21]. Local realism is therefore highly conditional on the measurement method, i.e. contextual.

Therefore cordus supports the 'pre-existing properties' concept of local realism, but not the 'independence of observation'. Cordus suggests it would be more helpful to disaggregate the two concepts. The aggregation is only meaningful if particles really are 0-D points.

The practical implication is that working scientists can continue operating under the assumption of local realism, as it is a sufficient approximation for many situations, but local realism as a whole is not supported.

Cordus refutes the 0-D point construct

Particules are proposed to have a 3-D structure of finite size, not 0-D points. If cordus is correct, then the 0-D point construct is severely wrong and a misleading concept that would need to be abandoned. Refuting the 0-D point idea, and all the construct built thereon, is an unorthodox position. But even within QM it is recognised that a single-particle interpretation is problematic [22].

We agree with Groblacher, et al. [12] that both locality and local realism need to be abandoned. From the cordus interpretation these two constructs are both dependent on the 0-D point premise, and therefore have a common mode of failure.

We suggest that concepts like 'locality' and 'local realism' are strongly framed by the underlying mental model of what comprises a particle. The default model of physics is for a particle to be a 0-D point, and that thought tacitly asserts itself into the higher level constructs. Thus Bell's theorem and all the other inequalities (e.g. Leggett) and all the further

[10] Local realism: that the properties of an object pre-exist before the object is observed, and independent of observation.

development and physical tests (including Groblacher et al), are founded on that tacit construct of 0-D points, and have to be interpreted in that context. Our results suggest that the paradoxes around 'locality' and 'local realism' are consequences of the 0-D point mental model, and may be resolved at a deeper level.

Bell's Loop

We join others [13, 14] in being critical of the way Bell's theorem has been used to perpetuate a general disbelief in hidden variables. There is nothing wrong with Bell's theorem, per se. It is just that it only applies to models, like QM, where particles are 0-D points. There is a circular logic in operation, see Figure 2, which reinforces the belief that particles are 0-D points and that quantum mechanics is the reality. Hence also that any weirdness is a problem of human perception rather than a fault of QM.

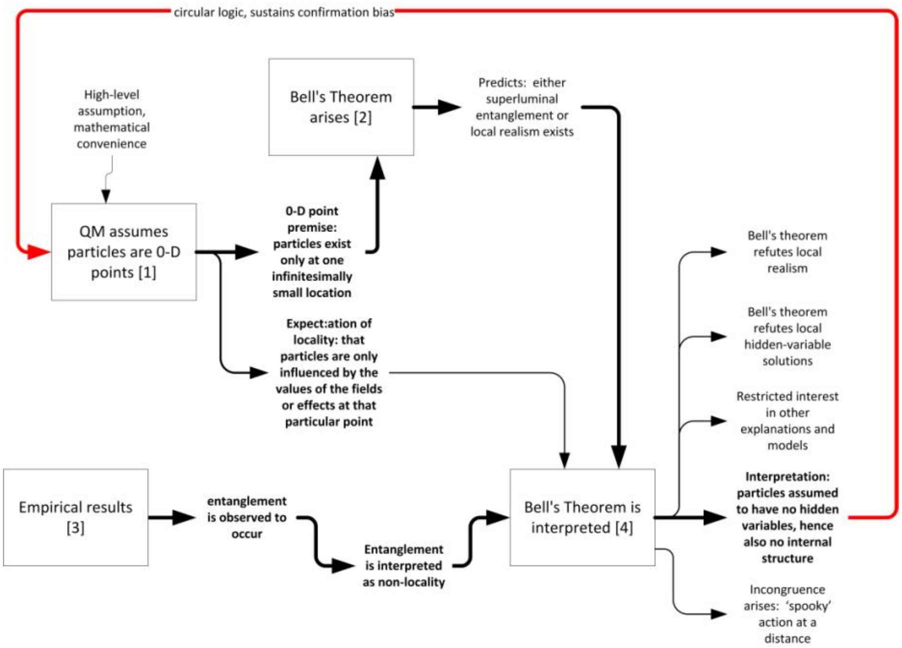

Figure 2: The assumption that particles are zero-dimensional structures is sustained by the interpretation conventionally made of Bell's theorem.

Referring to the figure, the root of the problem is the QM fixation on the 0-D point idea (1). More specifically, the corollary to the principle of locality is the principle that particles are 0-D points. It is not possible to have locality without a point at which to measure the fields and effects. Likewise, if there exists a simple 0-D point, then it can only be affected by the effects that exist at that point. The two ideas logically go together, but QM treats them as independent.

Bell's theorem is correct: either superluminal entanglement or local realism exists (2). Since entanglement is observed (3), it is reasonable to assume local realism does not exist. Where things go wrong in a logical sense is interpreting this as particles being unable to have internal variables (4). Wrong because it fails to recognise that local realism and the 0-D point construct go together. Denying locality but still retaining the 0-D point construct is not a logically consistent position, and QM's attempt to do so drives weirdness into its downstream interpretations. The interpretation (at 4) that particles cannot have internal variables then feeds back and reinforces the starting premise (at 1). So fundamental physics persists with the idea that particles must be 0-D points.

Thus there is problem in the conventional paradigm, one of selectively interpreting Bell's theorem as supporting quantum mechanics, and a corresponding failure to recognise the support the theorem gives for non-locality. As Laudisa observed:

> *'there seems to be a die-hard tendency to regard the Bell theorem as a result that does not establish non-locality but rather the impossibility of any objective ... account of the physical world, provided quantum mechanics is taken for granted.'* [14]

We suggest that the better interpretation of entanglement is that *both* local realism *and* the 0-D point construct are false. Some will argue that QM already does this, since it includes the idea of superposition. However that simply provides for *two* points, each of which is *still* zero-dimensional.

To break out of this circular logic it is simply necessary to observe that a 0-D dimensional point will, by definition, have local properties. That is simply a natural consequences of having no dimensions of geometry. Therefore, if locality fails then particles cannot be 0-D points.

5.3 Limitations of the cordus concept

The cordus conjecture is a conceptual model, not a finished theory. We acknowledge that we have simply made *functional provision* for the fibril to provide instant communication between the two reactive ends, but have not detailed *how* this superluminal effect might operate.[11] Another consequence of being a conceptual model is that the quantitative formulism is only nascent. We have not yet provided a comprehensive mathematical proof of the validity of the cordus idea.

It may seem strange to be presented with such an elaborate model of internal structures. Why this specific complex concept? Considering that it is a radical new concept ex nihilo and without precursors, what confidence can there be in its validity? Is all the complexity needed? We acknowledge these limitations and the difficulty of answering them. The cordus model is an artefact of the design process: we applied a design method and this where it logically leads. It is a candidate solution that is designed to be a sufficient solution to the phenomena under consideration. It is therefore parsimonious: there is no unnecessary complexity, and if it looks overly

[11] Other parts of the cordus conjecture offer a partial explanation: instantaneous communication within and between particules is the norm for synchronised particules, and time and the finite speed of light emerge as an artefact of discoherent states. Thus the speed of light is not so much a fundamental variable but a derived property. From the Cordus perspective the fine structure constant α is a measure of the transmission efficacy of the hyff-fabric, i.e. it determines the relationship between the electric constant of the vacuum fabric, and the speed of propagation c through the fabric.

complex that is because it includes features necessary to explain other phenomena that are beyond the present scope.

5.4 Implications for further research

What we have achieved here is to attempt a hidden-variable solution. We have produced one concept which we believe is fit for purpose, and have abandoned several others along the way. However we do not know whether this is the fittest concept. We can see that there is a family of candidate cordus solutions, all with two ended particules, but with different internal designs. We therefore consider this variant of the design to be a tentative solution, and subject to future revision. Thus there is a need to try out other concepts.

Another line of enquiry is attempting to increase the fitness of cordus-type solutions, by applying them to other phenomena, refining the concept, and constructing a more coherent framework with greater descriptive power. Some of that work has been attempted and the results suggest that the current cordus concept has good fitness. This is worth continuing for the potential to predict exciting new effects and causality (mechanisms). The quantitative formulism also needs work.

Quantum mechanics is so well established and supported by empirical evidence that it is generally held to be extremely reliable. Quantum mechanics already accepts non-locality and entanglement, so these features of cordus are not contentious. Yet the cordus conjecture suggests that QM is only a statistical approximation of a deeper determinism, and that the Copenhagen interpretation is profoundly wrong. Cordus is not simply an extension of QM, but a different concept altogether. Thus another line of future research is disproving the cordus conjecture.

6 Conclusions

The purpose of this paper was to look for *non-local* designs of particles. This has been achieved, and a candidate solution is proposed wherein particules consist of two reactive ends that are separated in space. The model provides for superluminal entanglement and predicts outcomes from Bell-type tests that are consistent with empirical results.

Cordus accepts superluminal entanglement effects as real and offers an explanation: that the fibrils of two particules become synchronised through mutual hyff interactions, called *complementary frequency state synchronisation*, such that changes to the one particle affect the other despite their physical separation or the internal stretch of the spans. Thus the instantaneous communication through the fibril provides the mechanism for internal consistency within the particule and superluminal synchronisation of response of its two reactive ends.

We suggest that the better interpretation of entanglement and the Bell-type theorems is that *both* local realism *and* the 0-D point construct are false. The cordus model disfavours the zero-dimensional point premise, and produces a new concept for the mechanism for locality and the extents thereof. Implications of the model are the need to abandon strict locality and local realism, at least at the deeper level. Nonetheless an approximate retention of both locality and realism is provided.

We have shown that the cordus conjecture provides a non-local hidden-variable model with predictions that are consistent with empirical results and the predictions of quantum mechanics. Our overall conclusion is that the Bell-type theorems are not proof against a hidden variable solution, and we have presented such a model complete with the first level of internal functional structures. New perspectives are provided on locality and local realism. The results suggest it is worthwhile questioning the established ideas of physics regarding the composition of particules, and we particularly identify the zero-dimensional point construct as ripe for revision. [12]

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[12] 'Concepts that have proven useful in ordering things easily achieve such an authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as 'necessities of thought,' 'a priori givens,' etc.' 'The path of scientific advance is often made impassable for a long time through such errors. For that reason, it is by no means an idle game if we become practiced in analyzing the long-commonplace concepts and exhibiting those circumstances upon which their justification and usefulness depend, how they have grown up, individually, out of the givens of experience. By this means, their all-too-great authority will be broken.' Einstein, 1916, "Memorial notice for Ernst Mach," Physikalische Zeitschrift 17: 101-02.

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