Internal mechanics of pair production: Remanufacture of discrete fields in a NLHV design

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Abstract

A theory is presented for the deeper mechanics of pair production. The specific area under examination is the conversion of a photon into an electron-antielectron (positron) pair. The theory is conceptual in nature and is developed within the non-local hidden-variable (NLHV) framework of the Cordus theory. The explanation is given in terms of the remanufacture of the evanescent discrete fields of the photon into the electric fields of the electron and antielectron, and the corresponding emergence of those particules. Secondary outputs are that the theory is able to qualitatively explain recoil dependency on photon polarisation, and give a physical explanation for electron holes.

Keywords: annihilation; two-photon physics; Bethe-Heitler; Breit-Wheeler; Standard Model

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1 Introduction

Pair production is the process of creating a particle-antiparticle pair from a photon [1]. A common process is two electrons producing an electron and positron (antielectron). Other possible outcomes include muon and tau pairs, and the elementary fermions (quarks and leptons) generally. Whatever the outcome, there needs to be enough energy in the system to produce those pairs, which for an electron at rest is 0.511 MeV, with the same again required for producing the antielectron. The pair production process may occur with a single (high energy) photon interacting with a nucleon (thereby providing a platform for conservation of momentum), or two photons interacting together. Pair production is an important process among the many others that occur in high-energy collisions involving atoms [2]. It affects other processes such as ionization. Furthermore, it contributes to energy loss in these impact situations, and also in supernovae.

Historically the primary research interest in pair-production has been the development of models for the outputs of the process for given input

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energy and situational variables, e.g. [3]. This has generally been very successful and current models permit an accurate prediction of outputs [4], as well as insights into the identities of the variables and the mathematical relationships between them. However there are still large unresolved questions at the foundational level, particularly about how the photon(s) transform into matter-antimatter pairs. From some perspectives, like the Copenhagen interpretation, it would be debateable whether such ontological questions were even relevant. Quantum mechanics (QM) treats particles as zero dimensional (0-D) points with intrinsic variables, and therefore doubts that there is anything inside the photon available to be *transformed* in the first place. However such an interpretation is to be expected, being merely self-consistent with the 0-D point premise. But for theories where particules have internal structure, i.e. hidden variable solutions, in these cases the question has more meaning. This paper applies a specific non-local hidden-variable (NLHV) solution, in the form of the Cordus theory, to the problem. It predicts the field transformations that would be necessary to convert a photon into a matter-antimatter pair. The specific area under examination is the creation of an electron-antielectron pair from two photons.

2 Existing approaches

Where two photons are involved, Quantum electrodynamics (QED) assumes that photons do not couple directly with each other, but instead one of the photons spontaneously fluctuates into a particle-antiparticle pair, and the other photon is absorbed into (couples to) one of those particles (*two-photon physics)*. The fluctuation is held to be a random event driven by the Heisenberg uncertainty principle. The particle-antiparticle pair is thought to comprise leptons or quarks, and their antiparticle, e.g. pion or kaon pairs. Feynman diagrams may be used to represent the input and output components of pair production.

The theoretical aspect of pair production that has received the most attention is the prediction of the relative likelihood of specific outcomes compared to others, with photons of different energy, hence *cross section*. Within that a particular focus area is the impact of a photon on an atom. Pair-production is one of several possible outcomes in such cases, others being Crompton scattering, and energy absorption, depending on the energy of the photon. At high energy the pair-production process dominates. This is commonly modelled as a perturbation interaction between the photon and an unbound electron described in plane waves, hence the Bethe-Heitler process [5]. The probability of pair-production occurring for various input energies is then determined, and this is the cross section σ. This may then be compared to empirical results. Typical features of the relationship are that pair-production only occurs above a threshold photon energy, and becomes steadily more likely as energy increases, before becoming constant as the process saturates [4]. Additional complexities arise with the electron being bound in an atom, and a screened vs. bare nucleus. The cross sections depend on the atomic number of the target. A close match to empirical results is obtained for light and heavy lepton production, though a number of other coefficients and tuning factors are required [2].

Pair production may also occur by the collision of two photons [6] (Breit-Wheeler model). Another production mechanism is collision of electron and laser beams, which involves additional mechanics due to the multiphoton collisions and interactions of daughter products with the beams [7]. Other situations that have been modelled include muons [8] and the inverse Cerenkov process [9]. Another area of complementary research is the creation of electron and electron-hole pairs in solids [10], with the input energy being plasmons as opposed to photons.

Almost all the progress has focussed on developing more refined mathematical models with better fit to empirical results. As for a deeper explanatory understanding of the mechanics, this is generally lacking. More specifically, although the current models describe *what* happens, the *how* is not described. For example, the Breit-Wheeler model describes the evolution of the electron pair as something that merely appears in the mathematics, that 'one finds that at a time t … the wave function contains a term which may be interpreted as referring to an electron '[6]. As Dirac observed, QM has the characteristic whereby it is 'usually easier to discover the equations that describe some particular phenomenon than just how the equations are to be interpreted' [11]. Others have continue to press the point that there are interpretational difficulties with the mathematical solutions for pair production [12]. Currently mathematical models, despite their excellence in identifying the relationships between variables and predicting the outputs, are approximations that treat particles *en-masse* in the form of beams (multi-photons). They do not address the discrete individual interactions between photons and matter [12].

There presumably must be substantial changes required to convert a photon into an electron. Apparently a photon does not simply halve itself to make an electron-antielectron pair. Or if it does, the conditions under which it does this are not evident. Part of the problem is that QM and the Standard Model assume that particules are zero-dimensional points, without internal structure. All the many variables that a particule is known to have, such as charge, spin, mass, are considered to be abstract intrinsic variables. This rejection of inner structure makes it impossible to contemplate pair-production as involving the remanufacture of internal structure, at least not from within the QM paradigm. Yet QM has no alternative explanation to offer. The situation is therefore an ontological singularity for QM. At the same time the Standard Model proposes that all interactions occur via exchange of specialised messenger particles, the gauge bosons, with that for electro-magnetism being the photon. So the photon has a dual and potentially conflicted role of being both the messenger particle, and the source for pair production, and it is unclear how those roles are differentiated.

Thus the mechanisms for converting a photon into a matter-antimatter pair are unknown. This is an obstacle to the understanding of many phenomena in fundamental physics, including asymmetrical genesis: if we do not understand the first stage of conversion into particle-antiparticle pairs, then it is going to be difficult to find where the asymmetry occurs. There is a need for theories that better explain the pair-production processes.

3 Purpose and Approach

The purpose of this work was to check whether pair-production can be explained from the non-local hidden-variable (NLHV) sector. This may not seem a promising sector in which to prospect for foundational solutions, given that it has historically included only one serious candidate, the de-Broglie-Bohm theory [13] [14] which has not progressed far. Furthermore, the Bell type inequalities [15-17] preclude *local* hidden-variable solutions, at least for 0D point designs. While no mathematical proof has yet excluded all *non-local* hidden-variable solutions, there is the practical problem that no new candidate solutions have arisen in that sector either. Consequently the whole hidden-variable sector is generally considered either non-viable or at least non-productive. Nevertheless the hidden sector has potential, demonstrated in recent developments of the Cordus theory [18]. This is a NLHV candidate solution, with a very specific design of internal structures. It has been used to explain many fundamental phenomena including wave-particle duality, unification, nuclides (H to Ne), and time [18] [19] [20] [21].

The approach in the present paper started with the NLHV design of the Cordus theory, specifically the matter-antimatter species differentiation [22], and the annihilation mechanisms [23]. These explanations are based in the concept that the nature of a particule, electron, photon, etc., is determined by its characteristic field structures, which are discrete. The re-allocation of these discrete forces has been used to explain the annihilation process [23]. The Cordus theory also has a methodology called HED mechanics that represents the principles for transmuting particles [24]. The name arises as it represents the states of the discrete fields or hyperfine fibril emission directions (HEDs). The present paper applies the same principles to the pair production situation.

4 Results

The present work is a logical extension of a prior concept for a NLHV design, and this is briefly explained first. Then we explain the proposed mechanics for manipulating discrete force structures, followed by application to the nuclear decays.

4.1 Cordus theory

The Cordus theory has been described elsewhere [24], and is only briefly summarised here. The core conjecture is that all particles have inner and outer structures comprising two *reactive ends* some distance apart (*span*), connected by a *fibril* (hence *cordus*), and emitting discrete forces [18]. This is called a *particule* to differentiate it from the zero-dimensional (0D) point idea of quantum mechanics (QM). The fibril is a persistent structure that provides instantaneous connectivity and synchronicity between the two reactive ends, but does not interact with matter. The reactive ends are energised sequentially (at the de Broglie frequency), during which they emit *discrete forces* out into the external environment. The locus of these over time defines a type of flux line called a *hyperfine fibril* (hence *hyff*). The discrete forces are emitted in three spatial directions (hence *hyff emission directions*, HEDs), and hence space is filled with a *fabric* of discrete forces [25]. The quantity, direction, and arrangement of these discrete forces determine the type of particule and are responsible for charge, mass, matter-antimatter species differentiation, and spin [22]. The discrete forces are responsible for the electro-magneto-gravitational and strong interactions, though the theory uses the term *synchronous interaction* in place of the strong, as this better describes the proposed nature of the interaction [19].

The resulting structures of the photon, electron, and antielectron (positron) are shown in Figures 1-3. Why these specific structures, as opposed to others? These are simply the structures that emerged from the systems design approach. We took the known functionality of the system (i.e. the empirical evidence of fundamental physics in the double slit device, among others), and then applied an iterative creative process to infer the inner structures that would be necessary and sufficient to explain those behaviours. These are the designs that emerged. This is an ex nihilo conceptual process that is not reliant on precursor concepts from QM, M- or any other theory. Hence it is somewhat unusual, even unexpected, and stands alone.

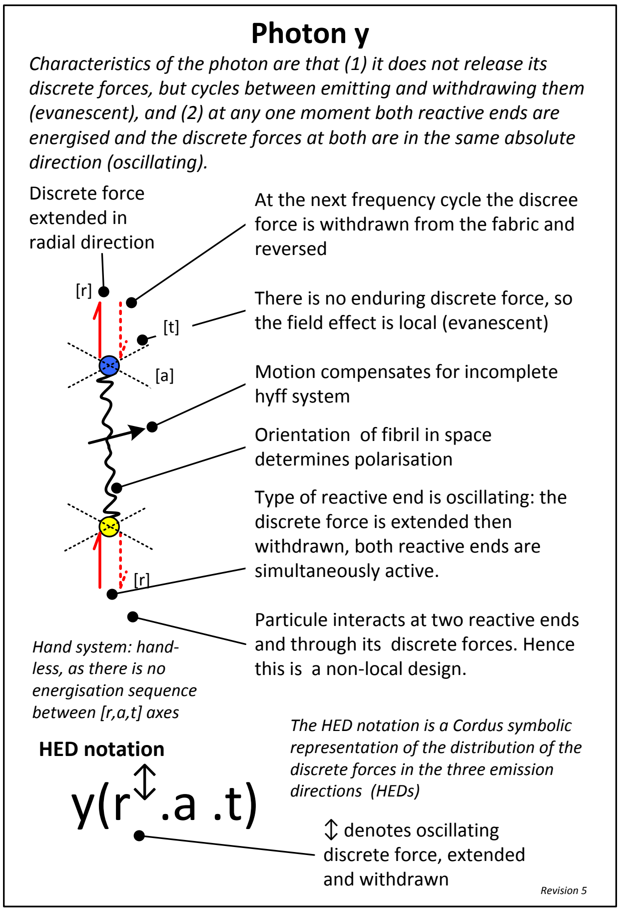

Figure 1: Proposed NLHV structures of the photon, according to the Cordus theory.

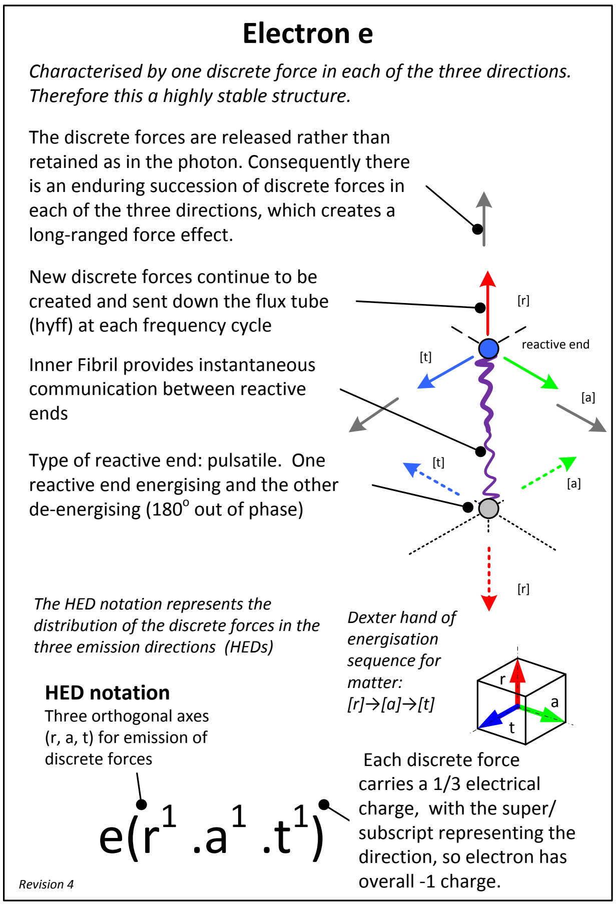

Figure 2: Proposed NLHV structures of the electron.

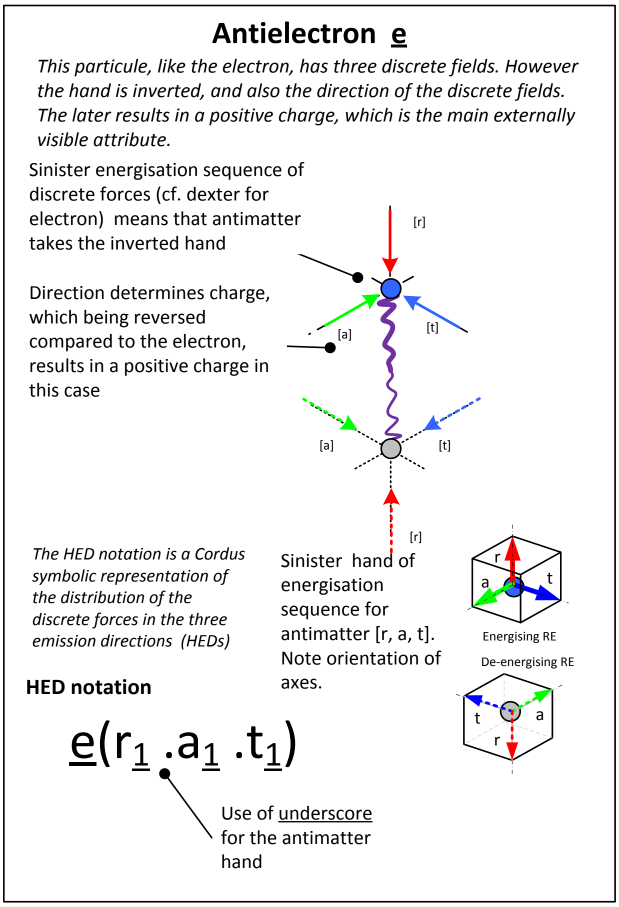

Figure 3: Proposed NLHV structures of the antielectron.

An initial analysis of the pair-production problem

Note the specific differences in the behaviour of the discrete forces between the photon and electron, as this is important in what follows. The photon emits and withdraws its discrete force in an oscillating manner (hence the evanescent field that scale as e^{-r}), whereas the electron continues to emit new discrete forces outwards (hence the electro-magneto-gravitational fields that scale as r^{-2}). Thus the nature of discrete forces emitted by the photon and electron are very different. This begins to explain why the photon and electron do not spontaneously transform from one to the other: they are not similar states that can randomly jump from one to the other in some Markov-like process. The next challenge is to explain how the transformation occurs.

4.2 Production of an electron-antielectron pair

Here we show how photons may be converted to an electron and antielectron. We represent this in two ways, first by considering the interactions of individual discrete forces, and then using HED notation.

The overall process is shown in Figure 4. This is a systems engineering representation in integration definition zero (IDEF0) notation [26] and shows a process with inputs at left of the activity block, outputs at right, and mechanisms entering from beneath.

Pair production is commonly represented as involving a single input photon interacting with matter, hence processes (6) and (7) in the figure. The absorption (6) and emission (7) interactions with matter can readily be represented in the NLHV framework of the Cordus theory [27]. Therefore we can put aside the initial matter interaction, and focus is on the subsequent transformation processes. The main pair production activities therefore start with two separate photons, each with oscillating reactive ends, that are close together (1). The proximity causes distress in access to emission directions (HEDs), and the reactive ends respond to these constraints (2). The mechanism by which they achieve this is renegotiation of emission directions. This requires the discrete forces and hence reactive ends, to change to accommodate. This is an application of the synchronous interaction (strong force) [19]. The reactive ends then develop 3D HED structures (3) in the [r, a, t] directions. Since HED emissions define the type of particule, new particule identities emerge (4) for the available HEDs. The discrete field structures (HEDs) separate into complementary hands, matter and antimatter [22]. This is driven by stability requirements. Consequently handed discrete force structures emerge, and these are the antielectron and electron emerge (5).

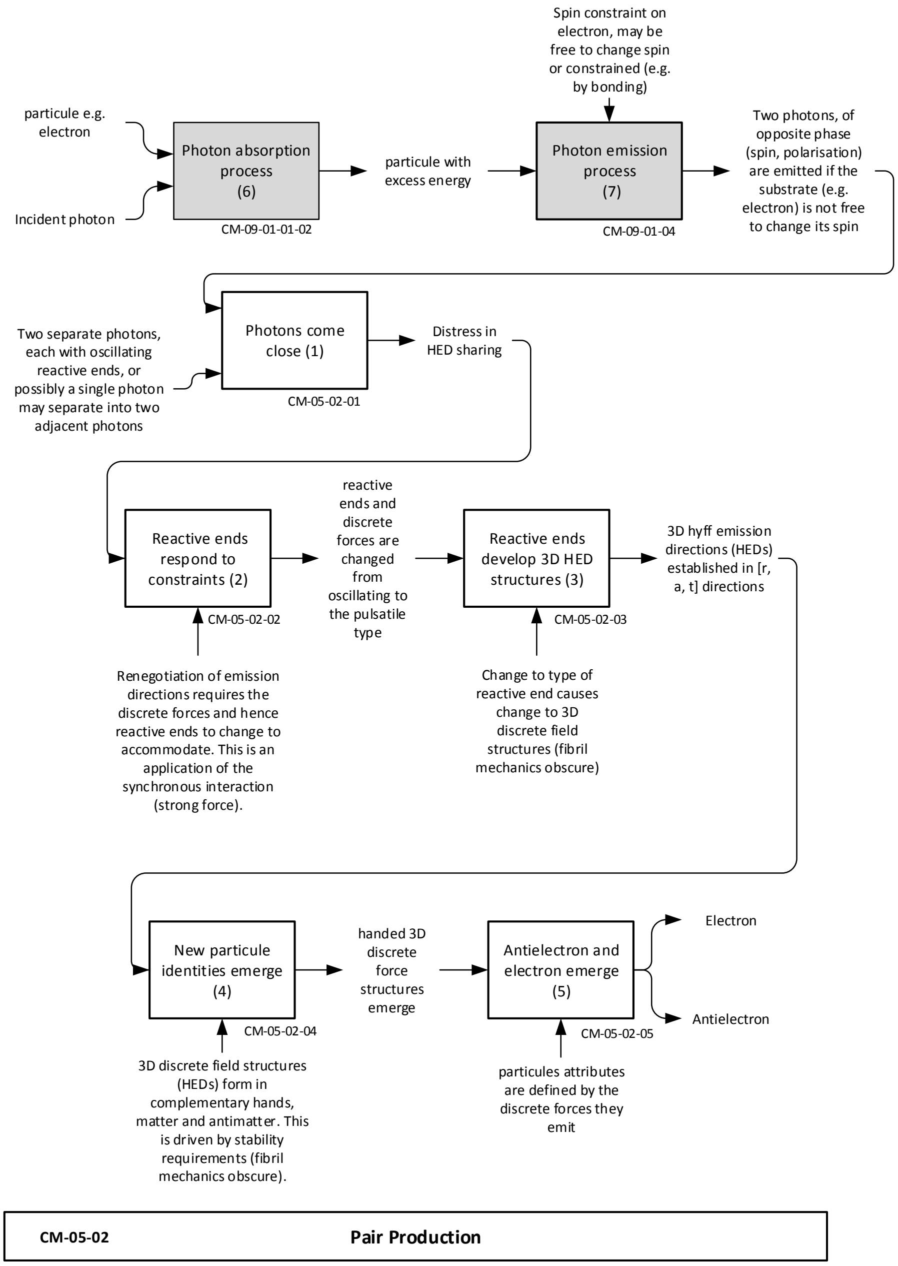

Figure 4: Proposed activities in the pair-production process.

The process is further detailed, at the level of discrete forces, in Figures 5 and 6 which show the proposed three-dimensional (3D) field-model. In essence, the incoming photons are unable to negotiate shared use of the field emission directions (HEDS) (1.3). Their difficulty is that the oscillating discrete forces are simultaneously active at *all* reactive ends, and are trying to recruit the same volume of space. To put it another way, the evanescent fields are in conflict. Nor can the photons evade each other. So they are forced to convert to the pulsatile type of reactive end instead (2.1). This type has one reactive end active and the other dormant, and it emits and releases its discrete forces (as opposed to recruiting a volume of space), so it is much easier to satisfy the constraints. The process also creates a new fibril to coordinate the new pairs of reactive ends (2.2). This type also requires three hyff, so a 3D field structure is set up (3.1) according to the hand system (4.1). The particule identities, electron and antielectron, emerge as a consequence of the changes to the discrete force structures (5.1, 5.2).

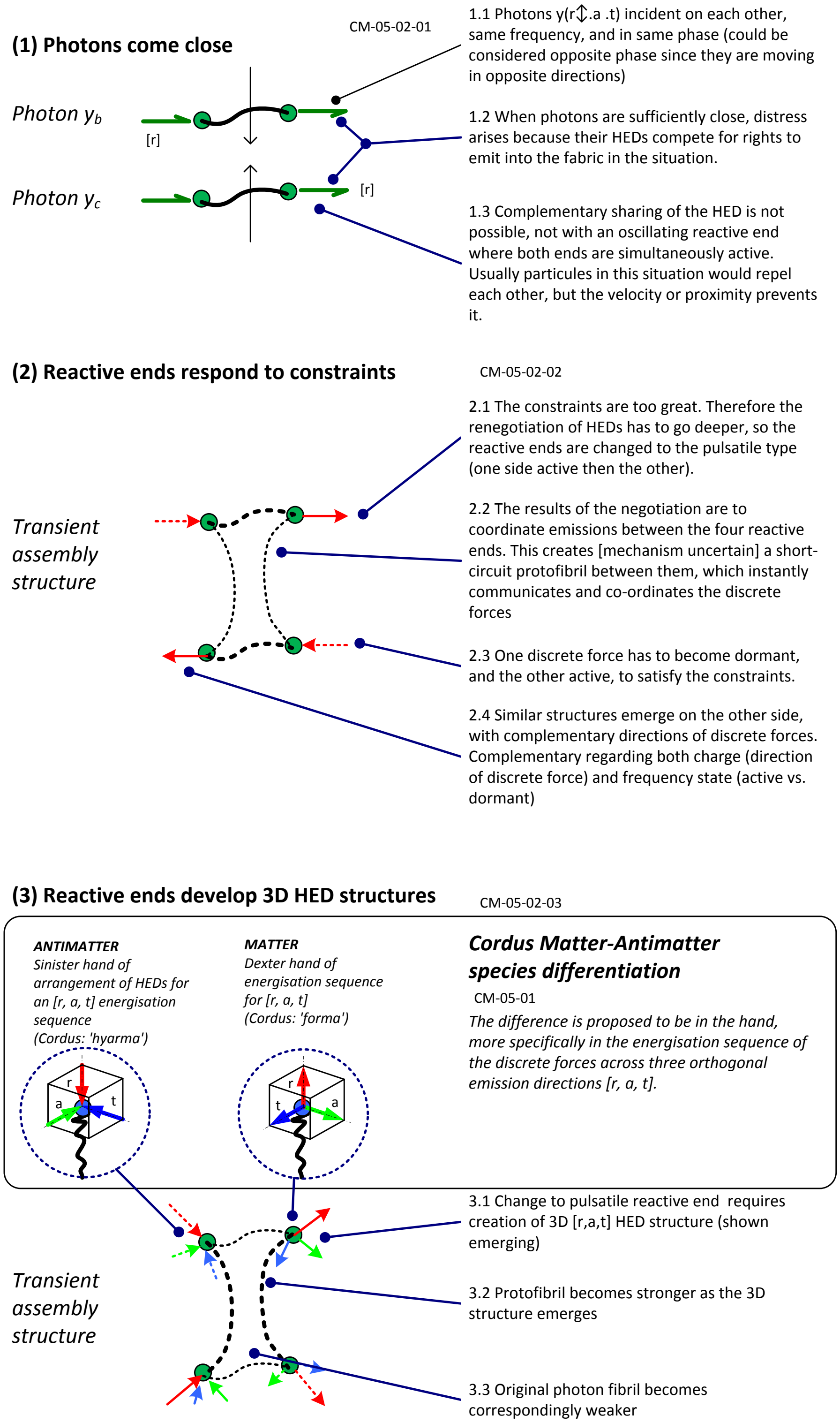

Figure 5: Details of the discrete force remanufacturing processes in the initial stages of pair production.

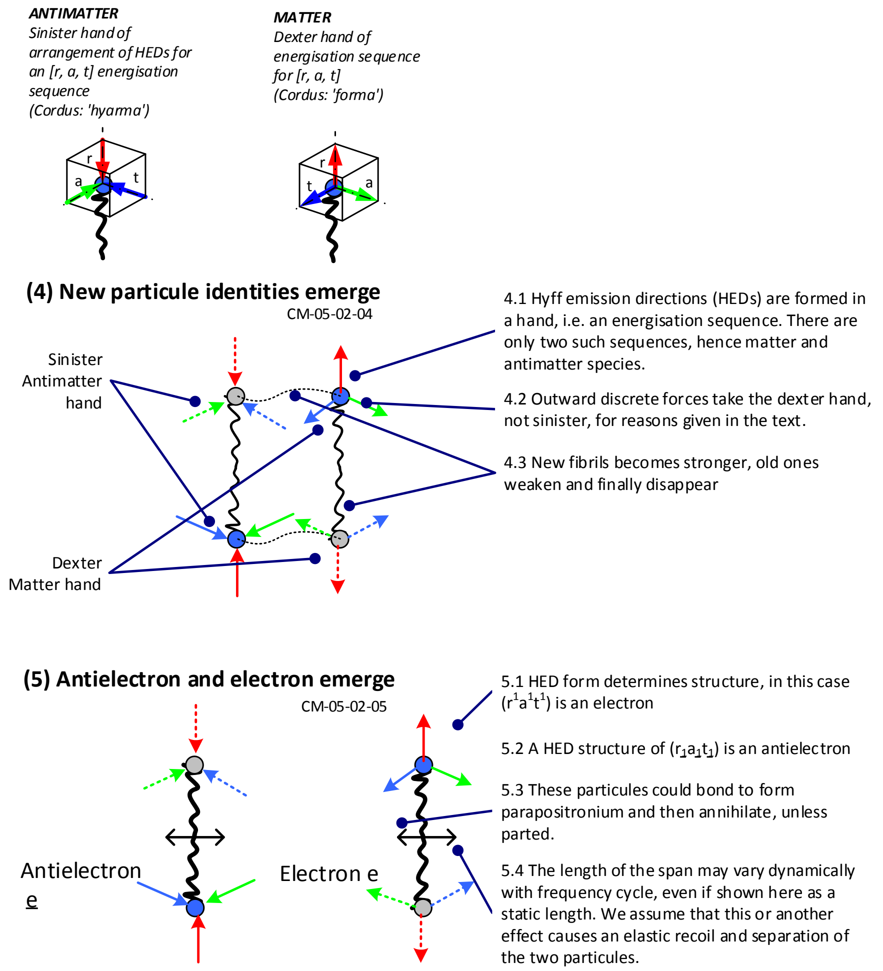

Figure 6: Further details of the discrete force remanufacturing processes in the later stages of pair production.

Examining the remanufacturing process at the level of discrete forces is interesting, and shows that it is possible to provide a natural explanation for pair production. However it is also useful to have a simplified representation of the process, which we provide next.

4.3 Simplified representation of pair production

Here we show a simpler and more efficient means of representing the process of pair production, using HED notation [24]. Application of the HED mechanics gives:

$$2y = y_b(r^{\updownarrow}\ .a\ .t) + y_c(r^{\updownarrow}\ .a\ .t) \qquad \text{(E1.1)}$$

$$=>\ O(r^1_{\underline{1}}\ .a^1_{\underline{1}}\ .t^1_{\underline{1}}) \qquad \text{(E1.2)}$$

$$=> e(r^1\ .a^1\ .t^1) + \underline{e}(r_{\underline{1}}\ .a_{\underline{1}}\ .t_{\underline{1}}) \qquad \text{(E1.3)}$$

$$=> e + \underline{e} \qquad \text{(E1.4)}$$

This is because previous work [24] identifies that two photons corresponds to a discrete force structure represented by ($r^1_{\underline{1}}\ .a^1_{\underline{1}}\ .t^1_{\underline{1}}$), hence the O transitional assembly above (E1.2). This assembly is driven by the synchronous interaction [19] to partition into more stable HED structures (E1.3). These structures, by inspection, are the electron and antielectron. Thus it is relatively simple to use HED notation to represent the overall remanufacturing process of pair production. The HED mechanics are for this NLHV design what Feynman diagrams are to QM, and the representations are not incompatible, though they have different levels of detail. The discrete force arrangements are the finest, then HED mechanics, then Feynman diagrams.

5 Discussion

5.1 Outcomes

We have provided a conceptual theory for how the evanescent field structures of the photons are reassembled into an electron and antielectron. What this demonstrates is that this specific NLHV design is able to offer candidate solutions at the foundational level. All of this is possible within one logically consistent set of qualitative mechanics from the wider Cordus theory.

5.2 Implications and interpretations

There are several parts of this theory that are curious and need commenting.

First, note that this theory requires two photons (not one) for the production of an electron-antielectron pair, and predicts that they need to be in complementary (opposite) phases. This may be testable.

Second, note that we assumed that the outward discrete forces take the dexter hand, not sinister, at 4.2. We do this to avoid the formation of the positive notElectron $!e(r_1 .a_1 .t_1)$ and negative antinotElectron $\underline{!e}(r^{\underline{1}} .a^{\underline{1}} .t^{\underline{1}})$ at step 5.2. We term these substances Not-Real matter. The selection of the Real as opposed to Not-Real production path may be justified by noting that under this theory the fabric of the universe, which comprises the discrete forces of all the particules in the accessible universe [25], is dominated by matter. Hence dexter-handed discrete forces prevail in the external environment, so it is natural that the pair-production process should be compliant therewith.

However the Not-Real matter is not fundamentally problematic. Instead it is interpreted as holes in a sea of coherent electrons (for !e) or antielectrons ($\underline{!e}$). If one electron is missing in a network of electrons in a superconductor, then the fields inside that hole correspond to the fields of the neighbouring electrons, but reversed. The hand of those fields is therefore unchanged. So according to the Cordus mechanics, this hole is not antimatter but an absence of matter, and behaves like a particule in its ability to move around. In other words these are empty locations where there are no reactive ends, but instead the discrete forces of the surrounding particules push in to the hole. Consequently the hole *does* have an electric field structure and can interact accordingly, though its life is bound up with the fluid of particules around it. In this way the conduction of current by holes is recovered by the Cordus theory. These holes have been physically observed, so that part is not contentious. The novel contribution is providing physical explanations for these structures.

This also suggests that pair-production should be possible *within* an electrical superconductor, and that the result will be holes, rather than matter per se. This may be testable.

This also means that the Cordus theory proposes another form of inversion to the existing two of charge, and matter-antimatter hand [22], this time an orthogonal Real vs. Not-Real species differentiation.

Third, note that the output electron and antielectron particules could bond to form parapositronium and then annihilate back to photons (5.3). See [23] for the corresponding Cordus theory for para- and ortho-positronium annihilation processes. To avoid annihilation, they must be parted before they form such bonds. We have not worked out the parting mechanism in detail. Our current concept is that an elastic recoil and separation of the two particules occurs, due to the way the span varies dynamically with frequency cycle (5.4). However this is tentative.

Fourth, note that this pair-production process has been developed for the case of a collision between two photons. Another common situation in which pair-production occurs is the collision of a photon beam with say an electron. We suggest this can be accommodated within the theory by assuming the electron absorbs and then re-emits the photon. There are then multiple routes to pair production: either (a) the electron emits two photons, (b) a single photon is emitted and collides with another photon in the incoming beam, or (c) the energy emitted by the electron progresses directly into the emission of the discrete field structures of another electron and an antielectron, without passing through the photon stage. Variants of these have been identified [28]. In this three-fermion process the original electron experiences a recoil, which either (b) or (c) could explain. However of more interest is the nature of the recoil, which is dealt with next.

Fifth, the theory explains the recoil. It has elsewhere been shown that the orientation of recoil depends on the polarisation of the incoming photons, and does NOT depend on the photon energy [28]. Such results are difficult to interpret using QM, for which polarisation is merely an intrinsic variable without physical embodiment. However the Cordus theory readily allows an appreciation of the issues, since the span of the particule is an important orientation variable. Thus the Cordus theory interprets both photon polarisation and electron spin as orientation of the main fibril of the respective particule. It is therefore natural to expect that the relative orientation of the photon and the target electron will determine the outcomes. In a similar way the Cordus theory has also explained basic optical polarisation effects such as Brewster's angle [18], though in those cases it is the relative orientation of the photon and the optical plane that is important (the optical plane is interpreted as an aggregate of the orientations of multiple electrons).

Furthermore, the Cordus theory for photon emission makes the interesting prediction that the photon is emitted in a direction orthogonal to the electron span [27]. Thus, it is understandable that the orientation of the photon, hence polarisation, will affect the recoil of the host electron. The Cordus theory therefore accommodates and conceptually explains why the recoil should be dependent on and transverse to the incoming photons [29]. This is consistent with the observation that 'the azimuthal distribution of the recoil electron is highly sensitive to the polarization of the incoming gamma radiation' [28], and the theoretical indications of polarisation-dependency shown by other authors [30]. Similar highly anisotropic recoil behaviour is also empirically evident in collisions occurring within an aligned molecular framework [29]. The dependency is so strong that it may be used in the inverse direction, as a measurement of photon polarisation [31]. Our comment in this regard is that the mathematical models predict the effect, and it is empirically observed. Yet an interpretation is difficult to make from within the 0D point paradigm, whereas this is much easier from the NLHV solution provided by the Cordus theory. Likewise known other minor effects, like heavier atoms being more prone to pair production, can also be more easily explained when particles are acknowledged to have physical size.

5.3 Limitations

We acknowledge the limitations of the Cordus model, particularly its conjectural nature. The whole of the Cordus conjecture could readily be falsified by showing empirically that there is no possible way that data support an interpretation of a particle having two ends as described. Another potential limitation is that the design method only gives *sufficient* solutions, not perfect ones, so there could be other designs that are better, and we fully expect this to be the case at a deeper level. Also, the detailed fibril mechanics at the next deepest level are incompletely understood, though they are not required here. We also acknowledge that the work lacks a mathematical formalism, though this is not so much a fundamental flaw as an incomplete part of the development, which has otherwise focussed primarily on the conceptual theory-building and large-scale coherence.

5.4 Implications for future work

There are several streams of potential future work. One is to give the mechanics a mathematical formulism. We have shown conceptually that quantum mechanics is recovered as a coarser probabilistic representation of a deeper Cordus determinism, and we would expect a mathematical formalism to likewise recover the QM mathematical machinery, if the theory is valid. Another work stream is that there is more conceptual work to be done. There are many other phenomena that might be analysed with the theory, and might in turn further expand the reach of the theory. We have only considered electron-antielectron pair production, and there are other outcomes to consider. There is also the whole landscape of pions, kaons, etc., to explore with this new theory. There are deeper questions to explore too: how the reactive ends transform, and the composition of the fibrils and discrete forces. At this point we simply propose their existence as necessary for the theory, and leave their elucidation for future work.

The next most immediate piece of work in this series is to analyse asymmetrical genesis. We now have a coherent set of explanations for pair production (this paper), beta decay processes [24], the internal structure of the neutrino [ibid], annihilation processes [23], synchronous interaction (strong force) [19], and internal structure of the nuclides (including hydrogen and helium) [20]. The conceptual building blocks are now in place to develop a candidate solution to the question of asymmetrical baryogenesis. We leave that to the next paper in this bracket.

6 Conclusions

A conceptual theory has been created within the NLHV framework of the Cordus theory, for the processes of electron-antielectron pair-production. The explanation is given in terms of the remanufacture of the discrete fields of the photon into those of the electron and antielectron, and the corresponding emergence of the inner structure of those particules.

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