

Asymmetrical neutrino induced decay of nucleons

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Abstract

Problem- The operation of neutrino detectors shows that nuclide decay rates can be affected by loading of neutrino species. However the underlying principles of this are poorly understood. **Purpose-** This paper develops a conceptual solution for the neutrino-species interactions with single nucleon decay processes. **Approach-** The starting point was the non-local hidden-variable (NLHV) solution provided by the Cordus theory, specifically its mechanics for the manipulation of discrete forces and the remanufacture of particle identities. This mechanics was applied to the inverse beta decays and electron capture processes for nucleons. These are situations where the neutrino or antineutrino is supplied as an input, as opposed to being an output as in the conventional decays. **Findings-** Inverse decays are predicted to be differentially susceptible to inducement by neutrino-species. The inverse β^- neutron decay is predicted to be susceptible to neutrino inducement (but not to the antineutrino). Correspondingly β^+ proton decay is predicted to be induced by input of energetic antineutrinos, but not neutrinos. Hence a species asymmetry is predicted. The inverse electron capture is predicted to be induced by pre-supply of either a neutrino or antineutrino, with different energy threshold requirements in each situation. The neutrino induced channel is predicted to have the greater energy barrier than the antineutrino channels. All the nucleon decay processes (forward, inverse, and induced) may be represented in a single unified decay equation, with transfers across the decay equality resulting in inversion of the matter-antimatter species (hand). **Implications-** The theory predicts the existence of a number of induced decays with asymmetrical susceptibility to neutrino-species. The results imply that detectors that measure β^- outcomes are measuring neutrinos, and β^+ antineutrinos. **Originality-** A new methodology is demonstrated for predicting the outcomes of decays and particle transformations. A unified decay relationship is proposed, that expresses all the conventional and induced decay processes. A novel prediction is made, that neutrino-species induce decay of nucleons, and that the interaction is asymmetrical. Hence also, that different decay types are affected differently by the input of energy and neutrino-species. A detailed explanation is provided of how this occurs at the level of the internal structures of the particules. This is an unorthodox outcome and is testable and falsifiable.

Keywords: neutron; decay; neutrino; antineutrino; detector; charged current interaction; asymmetry; physical realism

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1 Introduction

The subject here is the interaction of neutrino species with the decay processes, i.e. inverse decays. These form the basis of the neutrino detector schemes. However the mechanics are poorly understood and there is a need for a better theoretical understanding of the processes. This is also of practical importance given the inefficiency of current detectors. The paper develops a non-local hidden-variable (NLHV) explanation for these decays.

2 Literature

Detection of neutrino species

One type of neutrino detector operates on the *Cherenkov principle*. The neutrino-species strikes the detector material and results in an energetic electron, or more generally a charged lepton. The lepton emits Cherenkov radiation as it slows, which is detected. The common interpretation is that the momentum of the neutrino-species is transferred to the lepton. The Standard model uses the Z-boson and a neutral current interaction to accomplish this.

The charged current interaction process is routinely used to detect neutrinos in the *radioactive decay* type detectors. These detectors monitor the conversion rate of one element to another, e.g. chlorine ${}_{17}\text{Cl}_{20}$ to argon ${}_{18}\text{Ar}_{19}$ or gallium to germanium. Such reactions obviously involve the conversion of a neutron to a proton, (as opposed to changing the proton), so by empirical necessity there must exist a process whereby the impact of a neutrino species into a neutron produces a proton, in a type of inverse beta decay. However the decay process for the neutron is poorly understood from an ontological perspective (though well-documented empirically).

Beta decay of the neutron

Beta decays of the free neutron have been studied for a long time [1]. While any one experiment gives a reasonable accurate measure of the life of the neutron, there is poor agreement between experiments [2]. Whether this is due to intrinsic variability, measurement discrepancies, or hidden deeper mechanics, is uncertain. The conventional interpretation is that such results are systematic errors, and that decay rates are strictly constant. However the idea that the decay rates might not be fixed, but determined by other factors, is not excluded by the data. The identity of such factors is highly uncertain. Electromagnetic radiation would appear to be one factor affecting decay processes [3], but there may be others beside. There is also a possibility that neutrino-species interactions with matter extend to the decay of the neutron generally [4].

In summary, the decay rate of the free neutron is variable, for reasons which are not clear. Also, the nuclides used in neutrino detectors undergo neutrino-species induced decay, hence their decay rates are variable and dependent on the loading of neutrino-species. Taken together, this suggests that neutrino-species may induce decay, at least in the nuclides used in neutrino detectors and possibly more generally. However the mechanism is unknown, and it is this problem that the present paper attempt to solve.

3 Methodology

Purpose

Our purpose is to attempt an explanation of the interaction of neutrino species with the decay processes, i.e. neutrino-species induced inverse decay. This is worth doing for the ability to better understand the mechanics of neutrino detectors.

Context

The approach is to use a non-local hidden-variable (NLHV) physics called the Cordus theory. In an earlier era the idea that particles might have internal structure (hence hidden variables) was believed to be a promising alternative way of explaining quantum effects [5]. An early candidate solution was the de-Broglie-Bohm theory [6] [7], but this proved unable to contribute beyond a narrow application to wave-particle duality of the photon in the double-slit device. Subsequently quantum mechanics (QM) was developed, which is based on zero-dimensional (0-D) points and is therefore incompatible with hidden-variable solutions. These it rejects via the Bell type inequalities [8-11]. Nonetheless quantum theory has never managed to extinguish the possibility that particles may not be 0-D points after all. It is noteworthy that the inequalities do not preclude *non-local* solutions entirely. The Cordus theory exploits this.

The Cordus theory was developed by a systems design approach. It makes specific predictions of the internal structure of particles, and goes on to develop an extensive new physics around that concept [12]. The basic concept is that particles have two ends, as opposed to being zero-dimensional points.¹ The French term *particule* is used to distinguish these from the 0-D point kind assumed by QM. The two reactive ends are energised in turn and emit discrete forces in the process. The discrete

¹ Cordus theory: The core conjecture is that all particles have inner structures and outer discrete fields. A particule comprises two *reactive ends* some distance apart (*span*), connected by a *fibril*. The reactive ends emit discrete forces in a way that is specific to the particule, and hence the fields are fundamentally discrete. This is called a *particule* to differentiate it from the zero-dimensional point idea of quantum mechanics. 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 time 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 orthogonal spatial directions (hence *hyff emission directions*, HEDs), and thus space is filled with a *fabric* of discrete forces. 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. 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. See references for further explanation.

forces are emitted in three orthogonal spatial directions (hence *hyff emission directions*, HEDs), and thus space is filled with a *fabric* of discrete forces. Thus the fields are discretised. The provision of discrete fields means this is more than a NLHV design. See references for further explanation. The structure of the neutron² is shown in Figure 1, and the neutrino³ in Figure 2.

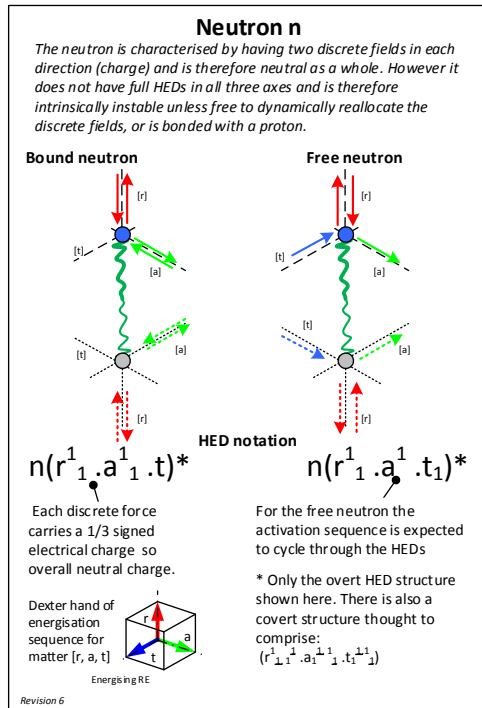


Figure 1: Proposed internal and external (discrete force) structures of the neutron. From [13], reproduced by permission.

² Neutron: The stability of the neutron inside the nucleus is caused by the complementary bound state with the proton. The neutron forms an intermediary between the protons. This assists the protons, as the discrete forces of the protons are otherwise incompatible. It also assists the neutron as it gives rise to a full complement of discrete forces at both ends of the neutron, and this gives it stability. In contrast, the free neutron is unstable since its discrete field structures, on their own, are incomplete. They are disturbed by external discrete fields that arise from the fabric. The neutron is proposed to have an overt component, which comprises the incomplete, but charge-neutral, discrete fields. These are represented in HED notation as $n(r_1^1 . a_1^1 . t_1^1)$. It is also proposed to have a covert component of a complete set of charge- and species-balanced discrete forces $(r_{\frac{1}{2}}^1 . a_{\frac{1}{2}}^1 . t_{\frac{1}{2}}^1)$. Superficially, these are not visible externally, but they are believed to contribute to the mass of the neutron, and to the fabric. By comparison the neutrino, has a similar set of external overt discrete forces, but has no covert component.

³ Neutrino: Main features of this theory is a proposition that the neutrino has incomplete coverage of all three emission directions, and consequently must move relative to the discrete forces of the fabric. It momentarily borrows discrete forces from the fabric to maintain its existence. It is propelled through the fabric by its imbalanced interaction with the fabric. The matter-antimatter species is determined, in this theory, by the activation sequence of the discrete forces, hence hand. Thus the neutrino and antineutrino have opposite energisation hands. The HED energisation sequence creates a corresponding spin angular momentum, the direction of which depends on the hand. Hence left-spin-hand arises from dexter hand energisation sequence. Consequently the spin of the neutrino species is linked, via the hand (energisation sequence) to the matter-antimatter species attributed. Thus the Cordus theory explains why the neutrino species move at the speed of light and have exclusive spin.

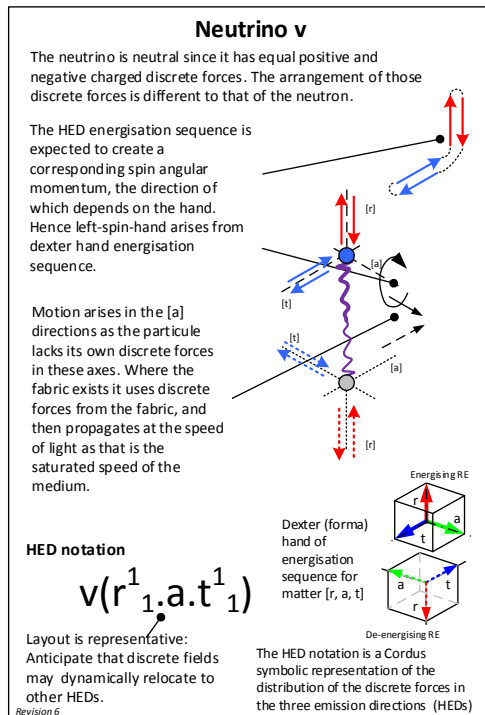


Figure 2: Predicted structure of the neutrino. From [13], reproduced by permission.

The Cordus theory explains a wide range of phenomena including genesis pair production & annihilation [14], asymmetrical genesis [15], the binding of nucleons (strong nuclear force) [16], and an explanation of the nuclides (H to Ne) [17]. The deconstruction of matter, i.e. the decay processes, have also received attention. The beta decays have been explained, as have the selective spin characteristics of the neutrino-species [13]. An explanation has been provided for the stability of the neutron within the nucleus and its instability outside, and the exponential life of the free neutron has been recovered [4].

Approach

The immediate prior paper in this bracket [4] proposed that the free neutron has two separate decay paths, which are mixed together in the β -process, with the first being determined by the local density of the fabric, and the second by the number of neutrinos encountered. The present paper extends this idea, by exploring how the mechanics could operate for neutrino-species induced decay of nucleons. In the conventional beta decays the neutrino or antineutrino is the *output*. This is inverted here, by exploring what happens when the neutrino-species is the *input*. This might seem counter-intuitive, but the existence of the reverse process is a logical necessity given that neutrino-detectors operate on the detection of decay by-products. The area under examination is impact with a proton or neutron, which is a simplification of the more complex nuclides used in detectors.

The method of analysis was to consider how the discrete force structures of the particules might change and be reassigned to new particules during

the decay process. The underlying premise of the Cordus theory is that a particule is defined by the pattern of discrete forces it emits, and therefore changes to the discrete forces cause the particule to change its nature. During an interaction the discrete forces can be redistributed and hence make up new particules.

HED mechanics

The Cordus HED mechanics describes the principles of these discrete force transformations, and provides a means to represent them. These rules correspond to conservation principles that are already accepted in other physical theories. The pattern of discrete forces is represented in a notation which indicates the number of discrete forces in each of three orthogonal spatial directions [r, a, t], their charge (negative: x^1 , positive: x_1) and matter-antimatter hand (antimatter uses underscore, e.g. $x_{\underline{1}}$). The principles of the HED mechanics are described elsewhere [13] [4]. Of special relevance are the following principles, which are repeated for completeness:

- A charge- and hand-neutral complex of discrete forces (z) may be added to any particule. It is analogous to QM's idea of a vacuum fluctuation. This neutral complex comprises $z = x_{\underline{1}}^1 x_1^1$ where x is one of the HED axes. The complex is represented symbolically by $\uparrow\downarrow$ where $\uparrow = x_1^1$ and $\downarrow = x_{\underline{1}}^1$. Being charge- and hand-neutral, this complex has no net energy. Note that neither a single discrete force (say) x^1 nor a single pair (say) \uparrow may be added to a particule ex vacua: all such additions must be neutral as regards *both* charge and hand. A discrete force complex is similar to the photon structure, but the two are currently considered different entities.
- The energy structure $\uparrow\uparrow\uparrow = [r_{\underline{1}}^1 \cdot a_{\underline{1}}^1 \cdot t_{\underline{1}}^1]$, which corresponds to a pair of photons (2y), may be added to a particule as part of energy absorption. This also corresponds to an electron-antielectron pair [14]. This interaction is an embodiment of the principle of mass-energy equivalence. The photon is denoted (y) and multiple (i) photons are denoted (iy).

The application of HED mechanics to a particule, or assembly of particules, is best understood as a rearrangement process. The discrete forces are permitted to change to other axes (HEDs), and make different groupings, and thereby redefine the identity of the particule. It does for hidden-variable interactions what Feynman diagrams do for interactions of 0-D points. The HED mechanics has been shown to successfully reproduce the beta decays and electron capture processes, including predicting where input energy is required [4, 13]. While this is not a complete validation, it does verify that the mechanics are consistent with the conventional decay processes.

An especially useful feature of the HED mechanics is its ability to *predict* the output particules from an interaction, by accounting for each discrete force. Consequently it is possible to predict the charges and matter-antimatter handedness of the output particules. This level of predictive power is not available in other theories. Also, the HED mechanics can

predict that photons (energy) are required as inputs to certain interactions, and produced as outputs in others, and this too is new and useful. This predictive ability provides a novel method for exploring unknown decay channels from first principles. Doing this assumes that the HED mechanics does apply beyond the situations for which it has successfully been tested, i.e. has external construct validity.

The HED mechanics were then applied to various inverse decay processes. A number of novel predictions arise *ab initio*. Since these are falsifiable, the validity of applying the HED mechanics in this way is testable. The results follow, and predict that the decays show preferential behaviour regarding the neutrino species.

4 Results: Neutrino-species interactions with nucleons

The possible effect of neutrinos and antineutrinos on several forms of decay are presented below. This is not an exhaustive analysis and it is still possible that other effects may exist: neutrinos may have other catalytic roles not represented by HED notation; and additional impacts with secondary particules could create different outcomes from these processes. See Table 1 for notation.

Symbolic notation

Symbol	Particule Identity	Cordus structure of discrete fields in HED notation	Comment
n	neutron	$n(r_1^1 . a_1^1 . t)^*$	Shown for bound state, where * denotes overt part.
p	proton	$p(r_{1.1}^1 . a_1 . t_1)^*$	* denotes overt part.
e	electron	$e(r_1^1 . a_1^1 . t_1^1)$	
\bar{e}	antielectron	$\bar{e}(r_1 . a_1 . t_1)$	positron
ν	neutrino	$\nu(r_1^1 . a . t_1^1)$	
$\bar{\nu}$	antineutrino	$\bar{\nu}(r_1^1 . a . t_1^1)$	
γ	photon	$\gamma(r_1^\updownarrow . a . t)$	\updownarrow denotes oscillating discrete force, extended and withdrawn
z	discrete force complex	$x_{1.1}^{1.1}$ or $\uparrow\downarrow$ where $\uparrow = x_{1.1}^1$ and $\downarrow = x_{1.1}^1$.	x is one of the HED axes [r.a.t]
2 γ	a pair of photons	$\uparrow\uparrow\uparrow$ $= [r_1^1 . a_1^1 . t_1^1]$	corresponds to an electron-antielectron pair
i	quantity, e.g. of photons	-	

Table 1: Symbolic notation.

4.1 Decay of the neutron (beta minus)

Forward β - decay process

The usual β - decay, which we term the *forward process*, is:



This has been explained elsewhere [13] in the Cordus framework. Next the inverse reactions are explored.

Inverse β - decay with an input neutrino

The addition of a neutrino at the start, is predicted to result in decay of the neutron to a proton and electron only (no antineutrino produced), as follows:

$$\begin{aligned}
 n + \nu &= n(r_1^1 \cdot a_1^1 \cdot t)^* + \nu(r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow &(r_1^1 \cdot a_1^1 \cdot t_1^1)^* \\
 \Rightarrow &(r_1^1 \cdot a_1^1 \cdot t_1^1)^* + (r^1 \cdot a \cdot t^1) \\
 \Rightarrow &p(r_1^1 \cdot a_1^1 \cdot t_1^1)^* + e(r^1 \cdot a \cdot t^1) \\
 \Rightarrow n + \nu &\Rightarrow p + e \tag{2}
 \end{aligned}$$

This contrasts with conventional β - decay (Eqn 1), hence this analysis suggests a process exists for neutrino-induced decay of the neutron.

Inverse β - decay with an input antineutrino

Supplying the antineutrino at the outset appears to also require two discrete force complexes:

$$\begin{aligned}
 n + \underline{\nu} + 2z & \\
 \Rightarrow &n(r \cdot a_1^1 \cdot t_1^1)^* + \underline{\nu}(r_{\underline{1}}^1 \cdot a \cdot t_{\underline{1}}^1) + [\downarrow_{\underline{1}}^1] \cdot [\uparrow_{\underline{1}}^1] + [\downarrow_{\underline{1}}^1] \cdot [\uparrow_{\underline{1}}^1] \\
 \Rightarrow &(r_1^1 \cdot a_1^1 \cdot t_1^1)^* + (r_{\underline{1}}^1 \cdot a_{\underline{1}}^1 \cdot t_{\underline{1}}^1) \\
 \Rightarrow &p(r_1^1 \cdot a_1^1 \cdot t_1^1)^* + \underline{\nu}(r_{\underline{1}}^1 \cdot a \cdot t_{\underline{1}}^1) + \underline{\nu}(r_{\underline{1}}^1 \cdot a \cdot t_{\underline{1}}^1) + e(r^1 \cdot a \cdot t^1) \\
 \Rightarrow n + \underline{\nu} + 2z &\Rightarrow p + e + 2\underline{\nu} \tag{3}
 \end{aligned}$$

However this outcome does not appear to have any advantage: the input neutrino simply comes out at the end again. Hence this inverse decay, while it is predicted to exist, is also predicted not to be induced by antineutrinos.

Compare Eqn 1 and β - decay Eqn 2: the theory predicts that a neutrino-induced β - decay channel exists. It is worth noting that the channel is asymmetrical: pre-supplying the antineutrino does not aid the β - process (Eqn 3). Hence the following finding:

It is predicted that a species asymmetry exists, whereby neutron decay is sensitive to the input loading of neutrinos, but not antineutrinos.

A companion paper [4] explains the decay of the free neutron, and proposed that the *cause* thereof is perturbation of the HEDs of the neutron by external discrete forces from the fabric. The decay rate is then predicted to depend first on the rate at which the neutron encounters external discrete forces, i.e. the fabric density ϕ . Based on the present work, it is proposed that a second factor affects the decay rate: the frequency at which the neutron encounters neutrinos specifically. The fabric density in our part of the universe can be expected to be high and approximately constant. However the neutrino loading could conceivably be more variable, due to the dynamics of local stellar processes. This is proposed as a candidate for the large variability in empirically determined neutron lifetimes [2].

4.2 Decay of the proton (beta plus)

Forward beta plus decay

The usual β^+ decay is:

$$p + 2\gamma \Rightarrow n + \underline{e} + \nu \quad (4)$$

where γ represents energy in the form of photons or vacuum fluctuations.

This decay is readily explained with the HED mechanics, including the necessity for input energy, see [13].

Inverse β^+ decay with an input neutrino

Supplying the neutrino at the input appears to also require energy in the form of two photons:

$$\begin{aligned} p + \nu + 2\gamma \\ \Rightarrow p(r_{1.1}^1 . a_1 . t_1)^* + 2\gamma(r_{1.1}^1 . a_1 . t_1) + \nu(r_{1.1}^1 . a_1^1 . t_1) \\ \Rightarrow p(r_{1.1}^1 . a_1 . t_1)^* + [\uparrow^1][\uparrow^1][\uparrow^1] + \nu(r_{1.1}^1 . a_1^1 . t_1) \\ \Rightarrow (r_{1.1}^1 . a_{11}^1 . t_1)^* + (r_{1.1}^1 . a_{1.1}^1 . t_1) + (r_{1.1}^1 . a_1^1 . t_1) \\ \Rightarrow n(r_{1.1}^1 . a_1^1 . t_1)^* + \underline{e}(r_{1.1}^1 . a_1 . t_1) + \nu(r_{1.1}^1 . a_1^1 . t_1) + \nu(r_{1.1}^1 . a_1^1 . t_1) \\ \Rightarrow p + \nu + 2\gamma \Rightarrow n + \underline{e} + 2\nu \end{aligned} \quad (5)$$

This outcome does not appear to have any advantage: the input neutrino simply comes out at the end again. Hence the inverse decay is predicted not to be sensitive to neutrino inducement.

Inverse β^+ decay with an input antineutrino

The HED analysis is shown below for an input antineutrino. The reaction apparently also requires one discrete force complex:

$$\begin{aligned} p + \underline{\nu} + z \\ \Rightarrow p(r_{1.1}^1 . a_1 . t_1)^* + \underline{\nu}(r_{1.1}^1 . a_1 . t_1) + [\downarrow^1][\uparrow^1] \\ \Rightarrow n(r_{1.1}^1 . a_1^1 . t_1)^* + \underline{e}(r_{1.1}^1 . a_1 . t_1) + (r_{1.1}^1 . a_1^1 . t_1) \\ \Rightarrow n(r_{1.1}^1 . a_1^1 . t_1)^* + \underline{e}(r_{1.1}^1 . a_1 . t_1) + [\downarrow^1][\downarrow^1][\downarrow^1] \\ \Rightarrow p + \underline{\nu} + z \Rightarrow n + \underline{e} + 2\gamma \end{aligned} \quad (6)$$

The results suggest the inducement of β^+ decay occurs under these conditions, with liberation of energy (two photons). This process complements Eqn 2, yet is not exactly symmetrical, since it is predicted to liberate energy in the form of the photons. The energy may not necessarily be emitted, as it could instead be absorbed and energise the neutron or antielectron. The mass-energy balance of Eqn 6 is not initially viable, since the mass of a proton is less than that of a neutron and antielectron. Consequently the energy of the input discrete force complex z would need to be high for this process to occur. This implies an energy barrier would exist.

Other work on asymmetrical genesis [18] identified another channel for antineutrino induced decay of the proton, this time with two antineutrinos plus a requirement for four input photons:

$$\begin{aligned} p + 2\underline{\nu} + 4\gamma \\ \Rightarrow p(r_{11}^1 . a_1 . t_1) + [\uparrow\uparrow\uparrow] + [\downarrow\downarrow\downarrow] + 2\underline{\nu} \\ \Rightarrow p(r_{11}^1 . a_1 . t_1) + [2\gamma] + [2\gamma] + \underline{\nu}_1(r_{1.1}^1 . a_1 . t_1) + \underline{\nu}_2(r_{1.1}^1 . a_1 . t_1) \end{aligned}$$

$$\begin{aligned}
&\Rightarrow (r_{11}^1 \cdot \underline{1.1} \cdot a_1 \cdot t_{1.11}^{\underline{11}}) + [4y] \\
&\Rightarrow \underline{e}(r_{1.1} \cdot a_1 \cdot t_1) + (r_{11}^1 \cdot \underline{1.1} \cdot a_1^1 \cdot t_1^1) + [4y] \\
&\Rightarrow \underline{e} + (r_{1.1}^1 \cdot a_1^1 \cdot t_1^1) + (r_{1.1}^1 \cdot a_1 \cdot t) + [4y] \\
&\Rightarrow \underline{e} + (\downarrow \downarrow \downarrow) + (\uparrow \downarrow) + [4y] \\
&\Rightarrow \underline{e} + 2y + z + [4y] \\
&\Rightarrow \underline{e} + 6y + z \tag{7}
\end{aligned}$$

Thus the theory predicts that the proton stability is asymmetrical regarding the neutrino species. The proton is predicted to decay preferentially under antineutrino inducement (more than one channel exists), but not for neutrinos.

The inputs and outputs of the antineutrino-induced β^+ decay are shown in Figure 3.

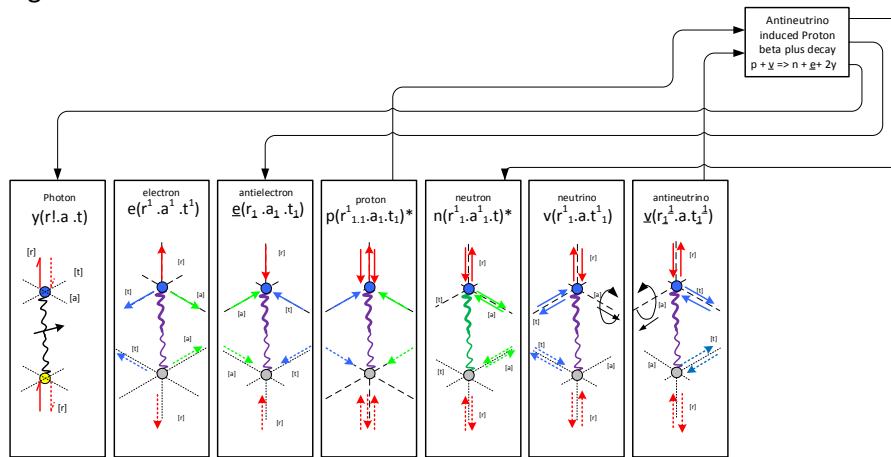


Figure 3: Proposed NLHV structures of the inputs and outputs to the antineutrino-induced β^+ decay.

So it is concluded that a species asymmetry exists, whereby the likelihood of β^+ proton decay is sensitive to the input of antineutrinos, but not neutrinos. There is also an energy barrier requirement to be overcome. This is opposite to the case for neutrons, where neutrinos are predicted to be the enhancers. This is a novel and potentially falsifiable prediction.

Hence the following finding:

It is predicted that a species asymmetry exists, whereby β^+ proton decay may be induced by input of energetic antineutrinos, but not neutrinos.

4.3 Electron capture

In electron capture (EC) a proton absorbs an electron and converts to a neutron, emitting a neutrino.

Forward EC

In the conventional process:

$$p + e \Rightarrow n + \nu \tag{8}$$

This has been explained by the HED mechanics, see [13]. Next we explore the induced decays.

Inverse Electron capture with an input neutrino

Pre-supplying the neutrino is predicted to have the following consequences:

$$\begin{aligned}
 & p + e + \nu \\
 \Rightarrow & p(r_{1.1}^1 \cdot a_1 \cdot t_1)^* + e(r^1 \cdot a^1 \cdot t^1) + \nu(r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + \nu(r_1^1 \cdot a \cdot t_1^1) + \nu(r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow & n + 2\nu \qquad (9)
 \end{aligned}$$

This outcome does not appear to have any advantage: the input neutrino simply comes out at the end again.

However when two discrete force complexes are added at input, then something interesting occurs:

$$\begin{aligned}
 & p + e + \nu + 2z \\
 \Rightarrow & p + e + \nu + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] \\
 \Rightarrow & p(r_{1.1}^1 \cdot a_1 \cdot t_1)^* + e(r^1 \cdot a^1 \cdot t^1) + \nu(r_1^1 \cdot a \cdot t_1^1) + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] + \\
 & [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] \\
 \Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + 2y(r_1^1 \cdot a_1^1 \cdot t_1^1) + 2y(r_1^1 \cdot a_1^1 \cdot t_1^1) + [r_{\perp}^1 \cdot a \cdot t_{\perp}^1] \\
 \Rightarrow & n + 4y + \underline{\nu} \qquad (10)
 \end{aligned}$$

Thus it is predicted that electron capture can be diverted to produce a neutron and an antineutrino (instead of the usual neutrino), and four photons. This might correspond to an especially energetic neutron or antineutrino. This implies that the EC inverse decay can be induced by an input neutrino, but an energy barrier must also be overcome.

Inverse Electron capture with an input antineutrino

Pre-supply of the antineutrino proceeds as:

$$\begin{aligned}
 & p + e + \underline{\nu} \\
 \Rightarrow & p(r_{1.1}^1 \cdot a_1 \cdot t_1)^* + e(r^1 \cdot a^1 \cdot t^1) + \underline{\nu}(r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + \nu(r_1^1 \cdot a \cdot t_1^1) + \underline{\nu}(r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow & n + \nu + \underline{\nu} \qquad (11a)
 \end{aligned}$$

The neutrino-species may take separate loci. Alternatively, if they combine then the reaction proceeds as follows:

$$\begin{aligned}
 \Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + (r_{\perp}^1 \cdot a \cdot t_{\perp}^1) + (r_1^1 \cdot a \cdot t_1^1) \\
 \Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] \\
 \Rightarrow & n + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] + [\uparrow_{\perp}^1] \cdot [\downarrow_{\perp}^1] \\
 \Rightarrow & n + 2z \qquad (11b)
 \end{aligned}$$

The process includes a stage involving the annihilation of a neutrino and antineutrino. The only overt outcome is the neutron, so we conclude that the antineutrino may facilitate this process. If so, this process permits the neutrino species to be dissipated into the background fabric of discrete forces. The process would increase the local fabric density. A comparable QM interpretation would be that the process creates a vacuum fluctuation in space-time.

However if a discrete force complex $[\downarrow_{\perp}^1] \cdot [\uparrow_{\perp}^1]$ is pre-supplied with the antineutrino, then a different outcome arises:

$$\begin{aligned}
& p + e + \underline{v} + z \\
\Rightarrow & p(r_{1,1}^1 \cdot a_1 \cdot t_1)^* + e(r_1^1 \cdot a^1 \cdot t_1^1) + \underline{v}(r_{1,1}^1 \cdot a \cdot t_{1,1}^1) + [\downarrow_1^1] \cdot [\uparrow_1^1] \\
\Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + v(r_1^1 \cdot a \cdot t_1^1) + \underline{v}(r_{1,1}^1 \cdot a \cdot t_{1,1}^1) + [\downarrow_1^1] \cdot [\uparrow_1^1] \\
\Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + (r_{1,1}^1 \cdot a_{1,1}^1 \cdot t_{1,1}^1) \\
\Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + (r_{1,1}^1 \cdot a_{1,1}^1 \cdot t_{1,1}^1) + (r_{1,1}^1 \cdot a_{1,1}^1 \cdot t_{1,1}^1) \\
\Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + 2\gamma(\uparrow\uparrow\uparrow) + 2\gamma(\downarrow\downarrow\downarrow) \\
\Rightarrow & n(r_1^1 \cdot a_1^1 \cdot t)^* + 2\gamma + 2\gamma \\
\Rightarrow & p + e + \underline{v} + z \Rightarrow n + 4\gamma \tag{12}
\end{aligned}$$

In this case the outcome is a neutron and four photons, without any neutrino-species. (Alternatively an energetic neutron.)

So it is concluded that the electron capture process has several inverse processes, with different results. The selection of process appears to be sensitive to the availability of energy in the form of discrete force complexes. These may correspond to vacuum fluctuations or photons. In summary the following finding:

The inverse electron capture is predicted to be induced by pre-supply of either a neutrino or antineutrino, with different energy threshold requirements in each situation. The Neutrino induced channel is predicted to have the greater energy barrier than the antineutrino channels.

4.4 Asymmetrical neutrino-species induced decay processes

The neutrino-species induced-decay processes for β^- , β^+ and electron capture are summarised in Table 2. Specifically, β^- neutron decay is predicted to be more sensitive to the input loading of neutrinos, β^+ proton decay to antineutrinos, and EC to both species.

Inverse decays	Neutrino pre-supplied	Antineutrino pre-supplied
beta minus decay (input: neutron + neutrino species)	Inducement to decay (Eqn 2)	No interaction
beta plus decay (input: proton + neutrino species)	No interaction	Inducement to decay (Eqn 6, requires input z)
electron capture (input: proton + electron + neutrino species)	Inducement to decay (Eqn 10, requires input 2z)	Inducement to decay (Eqn 11) (Eqn 12 with input z)

Table 2: Proposed input asymmetrical interactions between neutrino species and decay processes.

Thus there is predicted to be an asymmetry in the interaction of neutrino-species with nucleons. Note also that some of the interactions require the pre-supply of a discrete force complex (z). Consequently, not only is an asymmetry predicted, but it is expected to have a situationally-specific energy threshold too. Thus the inverse β^- decay is predicted to be induced

by input neutrinos on their own, whereas the inverse β^+ decay requires energy in addition to the antineutrino.

4.5 Manipulation of decay equations

Deeper principle

We infer a principle from the above asymmetries, which is that all the decay process-equations can be rearranged, with particles changing matter-antimatter species when transferred across the equality. For example, take the β^- decay of $n \Rightarrow p + e + \bar{\nu}$ (Eqn 1), and rearrange to find $n + \bar{\nu} \Rightarrow p + e$ (Eqn 2): note the change in hand of the neutrino-species. Similarly the β^+ decay, $p + \nu \Rightarrow n + e + \nu$ (Eqn 4) may be transformed to $p + \bar{\nu} \Rightarrow n + e + \nu$ (Eqn 6). Note that in this theory the matter-antimatter species are differentiated by hand, represented without or with underscore respectively. Hence the following finding:

Transfers across the decay equality result in inversion of the matter-antimatter species (hand).

The energy requirements may also be approximated by noting that the neutron is slightly heavier than the proton, so energy in the form of γ (photons) will be involved on the p side wherever p is not accompanied by e (exceptions are Eqn 6, where the p is provided with other structures instead, and Eqn 7 which does not involve n). By inspection, it is evident that this mathematics of manipulation holds for the decays discussed so far.

Bidirectional decay equations

This simple mechanics of manipulating decay equations permits an efficient representation. Furthermore, by representing the equality as bidirectional we can show both the conventional (forward) and neutrino-species induced decays in simple equations.

The first equation is:

$$p + e + \bar{\nu} \Leftrightarrow n \quad (13)$$

with β^- in the ' \Leftarrow ' direction, and antineutrino induced electron capture represented by ' \Rightarrow '.

Moving the neutrino-species across the inequality recovers the conventional electron capture equation:

$$p + e \Leftrightarrow n + \bar{\nu} \quad (14)$$

with EC represented by ' \Rightarrow ', and neutrino induced β^- by ' \Leftarrow '. These two equations represent β^- and EC, and the common thread is that both have p+e on one side and n on the other.

The third equation is:

$$p + 2\nu \Leftrightarrow n + e + \nu \quad (15)$$

with β^+ in the ' \Rightarrow ' direction, and neutrino induced neutron-antielectron capture in the ' \Leftarrow '. Moving the neutrino-species across the inequality gives another variant on this equation:

$$p + \bar{\nu} + \nu \Leftrightarrow n + e \quad (16)$$

with antineutrino induced proton β^+ decay in the ' \Rightarrow ' direction, and neutron-antielectron capture in the ' \Leftarrow ' direction.

Assuming the principle to be generally valid, it is simple to predict additional decays such as:

$$p + \underline{n} \Leftrightarrow \underline{e} + \nu + i\gamma \quad (17)$$

along with full inversions such as:

$$\underline{p} + \nu + i\gamma \Leftrightarrow \underline{n} + e \quad (18)$$

Many other applications are possible. This simple mechanics could be a useful way to prospect for particle interactions. It may be testable and falsifiable.

Unified decay equation

We therefore propose a unified decay equation for nucleons in the form of:

$$p + 2\gamma + iz \Leftrightarrow n + \underline{e} + \nu \quad (19)$$

where entities, other than photons, change matter-antimatter hand when transferred over the equality. This equation may be rearranged to represent β^- , β^+ , and EC in the conventional forward directions, and the induced decays too. Hence the following finding:

All the nucleon decay processes (forward, inverse, and induced) may be represented in a single unified decay equation: $p + 2\gamma + iz \Leftrightarrow n + \underline{e} + \nu$

5 Discussion

5.1 Outcomes

This work makes several novel contributions. The first is the methodological contribution of providing a way to *predict* the output particles from a decay process. This is achieved by accounting for each discrete force, via the HED mechanics. Consequently it is possible to predict the charges and matter-antimatter handedness of the outputs for new decays. Other theories do not have methods with this level of predictive power. Quantum chromodynamics does not predict how the decay processes work, and while Feynman diagrams can *represent* the inputs and outputs of known decays, they cannot *predict* the outcomes in novel situations. Nor can considerations of binding energy. A related contribution is that the HED mechanics has the novel ability of explaining the mechanism for mass-energy equivalence at the field level, and can thereby predict that photons (energy) are required as inputs to certain interactions, and produced as outputs in others.

The second contribution is the prediction that (a) neutrino-species induce decay of nucleons, and (b) the neutrino-species interact asymmetrically with the decay processes. Specifically it is predicted that prior provision of the neutrino facilitates β^- and EC decays, and the antineutrino facilitates β^+ and EC decays. This also means that the decays are predicted to be asymmetrical regarding the neutrino-species, and that situationally-specific energy thresholds apply. A systematic argument is provided in

support. These predictions are testable and falsifiable. This is a novel outcome as no other theory of physics predicts this.

A third contribution is the methodological proposition that any decay equation can be rearranged, with particles changing matter-antimatter hand when transferred across the inequality, and that all the nucleon decays may be summarised in one unified equation, see Equation (19). This was determined from first-principle considerations of the HED mechanics for discrete forces. It could be a useful high-level representation of the induced decay processes, because it is much simpler than applying the full HED mechanics. A comparable equation does not exist in conventional physics.

5.2 Implications

There are several implications of this, concerning detection of neutrinos, and the asymmetry of interaction between neutrino species and nucleons. This is an unorthodox claim and will need to be tested as its implications, if true, would be profound. Therefore to aid scrutiny the logic of the proposition is set out as follows:

1. Particles are proposed to have a specific non-local internal structure as described by the Cordus conjecture. This structure is consistent with the empirical evidence, is not precluded by the Bell-type inequalities, and explains quantum phenomena (e.g. wave-particle duality, superposition) in terms of physical realism where QM cannot.
2. It is assumed that a particle is defined by the pattern of discrete forces it emits, and therefore changes to the discrete forces cause the particle to change its nature. The Cordus HED mechanics describes the principles of these discrete force transformations, and provides a means to represent them.
3. The HED rules correspond to conservation principles that are already accepted in other physical theories. These are:
 - a. mass-energy equivalence, and
 - b. conservation of charge and matter-antimatter hand.
4. The HED mechanics produces results that are consistent with the empirical evidence for the conventional β^- , β^+ , and EC decays. It also predicts where energy is required or liberated from these decays.
5. Using the HED mechanics to predict the inputs and outputs of undiscovered decay channels assumes that the HED mechanics does apply beyond the usual decay situations for which it has successfully been tested, i.e. has external construct validity.

If any of these is wrong, then the outcome of this paper is in jeopardy. However if all these are true, and at this time there is no obvious reason to reject them, then the conclusion stands: that the neutrino-species interact asymmetrically with the decay processes.

DETECTION OF NEUTRINO SPECIES

There is empirical support for these proposed inducement equations. The equations can be understood as describing the underlying physics of the charged current interaction process which is routinely used to detect

neutrinos in the radioactive decay type detectors. Eqn 2 describes such a process. Regarding the Cherenkov type detectors, the Cordus theory has no conceptual difficulty in accepting that the elastic interaction of discrete forces between neutrino-species and an existing electron could accelerate the electron to the Cherenkov state.

NEUTRINO-LESS DOUBLE BETA DECAYS

Neutrino-less double beta decays ($0\nu\beta\beta$) are predicted by some theories and are an area of active experimental search [19] [20], usually in the context of exploring whether the neutrino is its own antiparticle (Majorana particle). Given the low reactivity of these particles, this is a difficult area to study. The HED mechanics suggests that pre-supply of an antineutrino to the electron capture process (Eqn 11b, 12) is a potential area to explore for neutrino-less outcomes. Nonetheless the Cordus HED mechanics does not support the interpretation of the neutrino itself being a Majorana particle, and instead proposes specific structures for the two species [13].

DO NEUTRINOS DECAY?

Neutrinos do not decay in the standard model, but they are predicted to do so in the extended model: the hypothetical right-handed neutrinos are theorised to decay to electrons. This would provide an asymmetric leptogenesis route, and then another hypothetical particle called the sphaleron would convert the leptons to baryons, and hence the asymmetrical predominance of matter over antimatter could arise. However these mechanisms are highly speculative. The Cordus theory offers a competing explanation. First, it explains why the neutrino-species are spin-selective [13]. This also means there is no need for a right-handed neutrino, which is consistent with the non-observance thereof. Second, it explains asymmetrical baryogenesis as a specialised decay (Cordus: remanufacture) of the antielectron, and at the same time explains asymmetrical leptogenesis [15]. The neutrino-species are proposed to have a special role, which is to remove unwanted matter-antimatter hand, but this does not involve their decay.

The concept of a free neutrino decaying is not supported in the current Cordus theory. There would seem to be nothing into which it could spontaneously decay. Instead the theory provides many channels for a neutrino to be arrested by impact with matter, with its discrete forces being remanufactured into other particules, or annihilating with an antineutrino.

ASYMMETRICAL INTERACTION BETWEEN NEUTRINO SPECIES AND NUCLEONS

Table 1 proposes an asymmetrical interaction between the neutrino family and the nucleons. Part of this asymmetry is already accepted, in that conventional β^- decay produces an antineutrino, whereas β^+ a neutrino. We identify that as a neutrino-species *output-asymmetry*. We propose there is also a corresponding *input-asymmetry*, whereby the decay proceeds differently depending on which neutrino-species is pre-supplied. This would have consequences for distinguishing between the two species at detection. It implies that detectors that measure beta minus outcomes are measuring neutrinos, whereas beta plus would be antineutrinos.

5.3 Implications for further research

The theory makes many testable and falsifiable predictions. It should be possible to test the perturbation mechanisms of decay that have been proposed here. It may also be possible to test the idea that neutrino species interfere with *some* decays but not others. Also, the energy thresholds are potentially testable. Other applications of the theory might be to the genesis asymmetry. Indeed that has been successfully demonstrated [15] since writing the first draft of this paper.

The current paper has focussed on the decay of single nucleons. Another area for future research is to determine the decay process for the nucleon that is *bound* in the nucleus. This is an even more complex situation since the nuclear structure is still uncertain, and there are many nuclides with different lifetimes. It is apparent from the sudden changes in life along any one isotope series, that the number of nucleons is not the primary determinant of stability. Consequently there is a need to explain the stability and decay process in the nuclides. Some preliminary work in this area has been completed, also using the Cordus theory [17].

Inter-nuclide variability in decay rates is one problem that needs solving, and intra-nuclide variability is another. Conventional physics interprets the decay processes to be independent of the external environment, hence expects constant half-lives. However the empirical evidence shows statistically significant variability in life of several nuclides. This also needs explaining, and it may be productive to consider whether neutrino-species sensitivity may be involved.

6 Conclusions

This analysis has identified a number of inverse decay process which are predicted to be induced by supplying the neutrino species as an input, as opposed to being an output to the decay. Unusually, these are found to be asymmetrical, i.e. the neutrino and antineutrino are predicted to react differently to the proton and neutron.

Summary of findings

1. It is predicted that a species asymmetry exists, whereby neutron decay is sensitive to the input loading of neutrinos, but not antineutrinos.
2. It is predicted that a species asymmetry exists, whereby β^+ proton decay may be induced by input of energetic antineutrinos, but not neutrinos.
3. The inverse electron capture is predicted to be induced by pre-supply of either a neutrino or antineutrino, with different energy threshold requirements in each situation. The Neutrino induced channel is predicted to have the greater energy barrier than the antineutrino channels.
4. Transfers across the decay equality result in inversion of the matter-antimatter species (hand).

5. All the nucleon decay processes (forward, inverse, and induced) may be represented in a single unified decay equation: $p + 2y + iz \Leftrightarrow n + e + \nu$

Author Contributions

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

Conflict of interest statement

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

References

1. Griffin, J.J., *Beta decays and delayed gammas from fission fragments*. Physical Review, 1964. **134**(4B): p. 817-823.DOI: <http://dx.doi.org/10.1103/PhysRev.134.B817>.
2. Wietfeldt, F.E. and Greene, G.L., *Colloquium: The neutron lifetime*. Reviews of Modern Physics, 2011. **83**(4).DOI: <http://dx.doi.org/10.1103/RevModPhys.83.1173>.
3. Salomaa, R., Aarnio, P., Ala-Heikkila, J., Hakola, A., and Santala, M., *Laser-enhanced radioactive decay and selective transmutation of nuclei revisited*. Energy Conversion and Management, 2008. **49**(7): p. 1910-1916.DOI: <http://dx.doi.org/10.1016/j.enconman.2007.09.026>.
4. Pons, D.J., Pons, A.D., and Pons, A.J., *Weak interaction and the mechanisms for neutron stability and decay* Applied Physics Research, 2015. **7**(1): p. 1-11.DOI: <http://dx.doi.org/10.5539/apr.v7n1p1>
5. Einstein, A., Podolsky, B., and Rosen, N., *Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?* Physical Review, 1935. **47**(10): p. 777.DOI: <http://link.aps.org/doi/10.1103/PhysRev.47.777>.
6. de Broglie, L., *Recherches sur la théorie des quanta (Researches on the quantum theory)*. Annales de Physique, 1925. **3**(10).DOI: <http://tel.archives-ouvertes.fr/docs/00/04/70/78/PDF/tel-00006807.pdf>.
7. Bohm, D. and Bub, J., *A proposed solution of measurement problem in quantum mechanics by a hidden variable theory*. Reviews of Modern Physics, 1966. **38**(3): p. 453-469.DOI: <http://dx.doi.org/10.1103/RevModPhys.38.453>
8. Bell, J.S., *On the Einstein Podolsky Rosen Paradox*. Physics, 1964. **1**(3): p. 195-200.DOI: <http://philoscience.unibe.ch/documents/TexteHS10/bell1964epr.pdf>.
9. Leggett, A., *Nonlocal Hidden-Variable Theories and Quantum Mechanics: An Incompatibility Theorem*. Foundations of Physics, 2003. **33**(10): p. 1469-1493.DOI: <http://dx.doi.org/10.1023/a:1026096313729>.
10. Groblacher, S., Paterek, T., Kaltenbaek, R., Brukner, C., Zukowski, M., Aspelmeyer, M., et al., *An experimental test of non-local realism*. Nature, 2007. **446**(7138): p. 871-875.DOI: <http://dx.doi.org/10.1038/nature05677>.
11. Colbeck, R. and Renner, R., *No extension of quantum theory can have improved predictive power*. Nature Communications, 2011. **2**: p. 5.DOI: <http://dx.doi.org/10.1038/ncomms1416>.

12. Pons, D.J., Pons, A.D., Pons, A.M., and Pons, A.J., *Wave-particle duality: A conceptual solution from the cordus conjecture*. Physics Essays, 2012. **25**(1): p. 132-140.DOI: <http://physicsessays.org/doi/abs/10.4006/0836-1398-25.1.132>.
13. Pons, D.J., Pons, A., D., and Pons, A., J., *Beta decays and the inner structures of the neutrino in a NLHV design*. Applied Physics Research, 2014. **6**(3): p. 50-63.DOI: <http://dx.doi.org/10.5539/apr.v6n3p50>
14. Pons, D.J., Pons, A.D., and Pons, A.J., *Annihilation mechanisms*. Applied Physics Research 2014. **6**(2): p. 28-46.DOI: <http://dx.doi.org/10.5539/apr.v6n2p28>
15. Pons, D.J., Pons, A.D., and Pons, A.J., *Asymmetrical genesis by remanufacture of antielectrons*. Journal of Modern Physics, 2014. **5**: p. 1980-1994.DOI: <http://dx.doi.org/10.4236/jmp.2014.517193>.
16. Pons, D.J., Pons, A.D., and Pons, A.J., *Synchronous interlocking of discrete forces: Strong force reconceptualised in a NLHV solution* Applied Physics Research, 2013. **5**(5): p. 107-126.DOI: <http://dx.doi.org/10.5539/apr.v5n5107>
17. Pons, D.J., Pons, A.D., and Pons, A.J., *Explanation of the Table of Nuclides: Qualitative nuclear mechanics from a NLHV design*. Applied Physics Research 2013. **5**(6): p. 145-174.DOI: <http://dx.doi.org/10.5539/apr.v5n6p145>
18. Pons, D.J., Pons, A.D., and Pons, A.J. *The preponderance of matter: Asymmetrical genesis via the antineutrino route*. vixra, 2011. **1111.0035**, 1-19 DOI: <http://vixra.org/abs/1111.0035>.
19. Ejiri, H., *Double beta decays and neutrinos*. Nuclear Physics B - Proceedings Supplements, 2001. **91**(1-3): p. 255-261.DOI: [http://dx.doi.org/10.1016/S0920-5632\(00\)00949-X](http://dx.doi.org/10.1016/S0920-5632(00)00949-X).
20. Simkovic, F., *Double beta decay: A problem of particle, nuclear and atomic physics*. Progress in Particle and Nuclear Physics, 2010. **64**(2): p. 219-227.DOI: <http://dx.doi.org/10.1016/j.pnpnp.2009.12.015>.