EXPLANATION OF THE TABLE OF NUCLIDES: QUALITATIVE NUCLEAR MECHANICS FROM A NLHV DESIGN

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ABSTRACT

It has long been expected in physics that there should be causality from the strong nuclear force to nuclear structures, but the mechanisms have been unknown. The present work addresses this problem, by developing a theory based on a non-local hidden-variable (NLHV) design, that explains the nuclides from the synchronous interaction (strong force) upwards. The basis of the Cordus nuclear theory is that the nucleus consists of a nuclear polymer bonded by the synchronous interaction (strong force). Three-nucleon physics are accommodated, in the form of bridge neutrons across the nuclear polymer. The requirements for nuclide stability are identified as the need to have a nuclear polymer that consists entirely of cis-phasic synchronous bonds, and also a spatially viable layout. Only certain identified layouts are viable. The Cordus nuclear theory successfully explains, for all nuclides from Hydrogen to Neon, why any nuclide is stable, unstable, non-viable or non-existent. It explains why some elements have multiple nuclides, and others only one. The theory also explains the deviations from the p=n line, why 1H0 and 2He1 are stable with low neutron counts, why 4Be4 and 9F9 are unstable, and why heavier elements require more neutrons than protons for stability. It explains relative stability (lateral trends with one nuclide series), including the anomalous progressions (i.e. those situations where one nuclide is unexpectedly much more or less stable than its neighbouring nuclides). The theory also explains why the limits of stability are where they are. It explains the patterns of stability in the table of nuclides, such as the runs of stable isotopes and stable isotones. Thus the nuclide landscape may be explained by morphological considerations based on a NLHV design.

Keywords: nuclides; isotopes; nuclear physics;

1 INTRODUCTION

The nucleus continues to be a mystery, a century after Rutherford's discovery thereof (Rutherford, 1911) and despite the subsequent development of quantum mechanics (QM), the Standard Model, and quantum chromodynamics (QCD). It is a logical necessity that the strong nuclear force should be a causal factor in atomic structures, but the mechanisms are still obscure. There are several models for nucleus structure, but each only provides a part-solution, and none explain all observed effects (Elliott, 1985). It seems likely that the models are approximations to a deeper and more complete theory. Finding that new theory, or alternatively finding a way to unify the existing models, is worth attempting for the potential to yield a more complete understanding of matter and chemistry.

One of the challenges that needs overcoming is that none of the existing theories, including QCD, are capable of explaining the causality from the strong force upwards to the bonding of protons and neutrons in nuclear structures. A further problem is that the elements have many nuclides, and there is a need, at present unfilled, to explain why any given nuclide is stable or unstable, and explain anomalous states (e.g. the instability of 4Be4). Related to this is the need to explain the trends in the table of nuclides, e.g. why the drip lines are where they are, why the series stop where they do. Current explanations in this area, e.g. magic numbers, lack explanatory power. A further need is to describe the quantitative features of the nuclides, such as their lives and binding energy, and the trends therein. It is in this area that the most developments have taken place, in the form of models: mathematical fits to the data. However even so the fit is incomplete: the models provide a smooth fit to (say) binding energy, but the real data are discrete and disjointed. The mismatch is particularly apparent for light elements.

The present paper addresses some of these problems, by presenting a novel theory for nuclear structure, one that is able to explain the nuclides from the fundamental strong force upwards. This is not a unification of existing models, but a development based on new principles from the non-local hidden-variable (NLHV) sector, specifically the *particule* structure of matter proposed in the Cordus theory (D. J. Pons, A. D. Pons, & A. J. Pons, 2013b).

2 EXISTING APPROACHES

2.1 HISTORICAL DEVELOPMENTS

Early models of the atom treated it as a continuous substance without structure, but that changed once the electron was discovered by Thomson (Thomson, 1904) in 1897. Thereafter the atom was proposed to consist of a mix of negative and positive charge, hence Thomson's *plum-pudding* model. Thomson conceived of 'motion of a ring of *n* negatively electrified particles placed inside a uniformly electrified sphere' (Thomson, 1904). However the structure of the positive charges was left unspecified. Of similar vintage was Lewis' cubical atom model, which proposed that the atom was a cube with the electrons, hence bonds, at the corners (Lewis, 1916). Rutherford showed empirically by the gold foil experiment that the positive charges must be concentrated in the centre of the atom, not distributed throughout (Rutherford, 1911). That central region came to be called the nucleus. The Rutherford model led to the Bohr model (Bohr, 1913) of a central nucleus surrounded by orbiting electrons. Importantly, those electrons were proposed to be in stationary orbits, i.e. discrete energy shells in which they could move with lossless motion, with quantum jumps in energy between levels (Bohr, 1913). However the structure of the nucleus itself was still not modelled. The next developments also focussed on the structure of the electron shells: how many electrons could be contained in each shell (two, eight, etc.), and what the order was for their successive filling. Chemical bonding then became understood in terms of the availability of electrons in valence shells (Lewis, 1916). Thereafter quantum mechanics developed from de Broglie's understanding of the wave-particle nature of electrons (de Broglie, 1925), Heisenberg's proposal about the intrinsic uncertainty of knowing both the position and momentum of an orbiting electron (Heisenberg, 1925), and Schrodinger's development of the wave function to represent the standing waves where the electron was most probably located (Schrödinger, 1935). The concept arose of electrons occupying specifically shaped orbitals, rather than orbiting in a planetary fashion as formerly understood. This thinking then affected the models for the nucleus.

2.2 MODELS OF THE NUCLEUS

Much is known about many of nuclides, such as their half-lives and binding energy. Trends are discernable, for example the obvious need for an increasing number of neutrons as the number of protons increases. The main existing models of the nucleus are binding energy, shell model (Ivanenko, 1985), liquid-drop model (Gamow, 1930), and semi-empirical mass formula (Weizsäcker, 1935), with their derivatives.

BINDING ENERGY

The binding energies of nuclei are generally known, so the energy emitted by or required for a decay process is also known. This may be used to explain why certain decay reactions do occur, and others not. The boundaries for stability are known, and represented as nuclear drip-lines. These show the trends for where the nucleus is instable and will release/dispose of a proton or neutron (or alpha particle in some cases), hence 'drip'. This can be explained by the binding energy, i.e. the extent to which the system is at a lower energy state by moving the nucleon outside the nucleus. Binding energy also usefully explains the trends in absorption and emission of energy at nuclear reassembly. For elements up to iron the fusion assembly of lighter elements liberates energy. After iron the assembly requires energy, and disassembly (fission and alpha decay) releases energy. This is explained in terms of the interaction of the competing effects of the strong nuclear force and electrostatic repulsion, with the latter dominating for larger nuclei. This also is the explanation for the absence of stable nuclei above 82Pb. However, knowing the binding energy is insufficient as an explanation for why specific nuclides have the binding energies they do. A further, and more serious limitation, is that binding energy does not correlate exactly with the stability of nuclides, and is altogether incapable of explaining sudden changes in the series. This limitation is particularly apparent in the lighter elements. Nor does it explain what the structure of the nucleus might be. For that, the shell and other models are better.

SHELL MODEL

The concept of the nucleus consisting of protons and neutrons was proposed by Ivanenko in 1932 (Ivanenko, 1985) and thereafter the idea of energy levels was subsequently applied by him and others to develop a shell model for the nucleus. This model provided shells for protons and neutrons independently. The shells were determined from assuming a harmonic oscillator in three coordinates. The elements display particular stability for certain quantities of nucleons, hence 'magic numbers'. These numbers are successfully predicted by the shell model, providing that some tuning is done by including a spin-orbit interaction. This model also predicts stability for large atoms (hence 'island of stability') beyond the current range of synthesised elements, though the predictions vary with the particular method used. The shell model has good fit for atomic numbers below about 50, but becomes unwieldy for high atomic numbers.

The shell model has been extended to the interacting boson model (IBM) wherein nucleons are assumed to exist in pairs (Otsuka, Arima, & Iachello, 1978), hence the model is restricted nuclei with even numbers of protons and neutrons (Pfeifer, 1998). This simplification reduces the complexity of the shell model and thereby extends it to heavier nuclei. The IBM lacks a rationale at the microscopic level (Elliott, 1985). Another extension to the shell model is the cluster model, which assumes that the nucleons form closely-packed clusters (Pauling, 1965). The clusters, or *spherons*, are proposed to consist of aggregates of neutrons and protons, typically alpha particles of two protons and two neutrons. Packing these in three-dimensional space leads to shells and sub-shells, and an explanation for magic numbers. The cluster model also explains why some nuclei are elongated into highly deformed states rather than being spherical.

Liquid-drop model

The liquid-drop model, originated by Gamow, assumes that the nucleus is comparable to an incompressible fluid made of nucleons (Gamow, 1930). It predicts the binding energies and the shape of the nucleus, but not the magic numbers. It is analogous to surface tension in the way it treats the interior nucleons as behaving differently to those on the surface. An extension is the semi-empirical mass formula (SEMF) (Weizsäcker, 1935) which uses coefficients of empirical origin (see below). Another variant of the drop idea is the Collective model, which seeks to represent the collective dynamic motion or vibration of the whole set of nucleons comprising the nucleus (A. Bohr & B. R. Mottelson, 1953; Aage Bohr & B. R. Mottelson, 1953; Peierls & Yoccoz, 1957; Villars, 1957). It has been successful in explaining energy levels, where there are even numbers of protons and neutrons (i.e. no valence particles).

Semi-empirical mass formula (SEMF)

The semi-empirical mass formula (SEMF) (Weizsäcker, 1935) is based on Gamow's liquid-drop model (Gamow, 1930), and is particularly effective at predicting the binding energies and boundaries of nuclide stability (drip-lines). The factors in this model are the strong nuclear interaction (volume of whole assembly), electrostatic repulsion, surface energy (lower binding energy assumed for nucleons on the outside of the assembly), asymmetry of state (neutron and proton counts are not the same), spin state (pairing of particles in even-numbered assemblies gives greater stability), and several empirically derived calibration coefficients.

This model is interesting in the way it anticipates an underlying theory for stability, albeit empirically rather than descriptively. Thus the strong nuclear force (the first term above) is believed to have only a small range, such that nucleons interact with their immediate neighbours but not those further away in the assembly. The binding energy of the strong force is therefore modelled as increasing linearly with nuclear size (volume), not in proportion to the total number of nucleons. The third term, for surface area, moderates this neighbourliness factor on the basis that nucleons on the outside surface of the drop do not have as many neighbours with which to bond in the strong force. The other major factor in the SEMF is the charge, whereby it is proposed that mutual repulsion occurs with increasing number of protons, caused by electrostatic (coulomb) repulsion. This factor assumes a uniform charge in a spherical nucleus. The SEMF treats the nucleus as a ball of nucleons: it does not differentiate between protons and neutrons other than in the charge-factor, but primarily focuses on *volume*. This is consistent with its origin as a liquid-drop model.

The SEMF is successful in broadly predicting binding energies. It achieves this by fitting a type of power series with *volume* as the primary term, and five calibration coefficients available for tuning. Therefore there is some uncertainty as to how much of its success is merely a consequence of calibration, as opposed to a correct interpretation of the underlying physics. Therefore, while being open to the factors and causality that it suggests, it is also possible that nuclei might not really work this way. Other limitations of the SEMF are that it offers a smooth model, and fails to represent the underlying discrete nature of the nuclides. Nor does it represent the oddities and discontinuities in the series. Also, the fit is poor for the light nuclides. Furthermore, the modelling is focussed on binding energy, which is a poor discriminator between stability and instability.

LIMITATIONS

Existing models provide mathematical approximations for key nuclear characteristics. They identify the interplay of the strong and electrostatic forces as important in determining stability, but without elucidating the causality from the strong force to nuclear characteristics. Nor has integration of multiple models been possible. None of the models describe the detailed interaction of the nucleons, so the internal arrangements of the nucleus are still a mystery (Pfutzner, Karny, Grigorenko, & Riisager, 2012). There is an obvious causal insufficiency to QCD and the shell/drop/SEMF models, despite a historically large investment of effort. The key questions are: How is it that a variable number of neutrons can be bound to one set of protons? Why are some combinations stable and others not? Why are proportionately more neutrons required as more protons are involved? These are difficult questions, which existing theories cannot answer.

3 PURPOSE AND APPROACH

PURPOSE

The purpose of this paper is explain the Table of Nuclides from fundamental principles. More specifically, we seek to describe why any one nuclide is stable, unstable, or non-existent, starting from the strong force. There are also other behaviours that the solution must accommodate: why the deviations from the p =

n line occur where they do (and not elsewhere), and why any one series (all the nuclides for an element) start and stop where they do (position of the drip lines).

APPROACH

This is an ambitious endeavour, and we address it in stages. We start with a specific NLHV design for the internal structure of matter, called the Cordus *particule* (Dirk. J. Pons, Pons, Pons, & Pons, 2012). A hidden-variable approach offers mechanics that are unavailable within the zero-dimensional point framework of quantum mechanics, and the non-local design circumvents the Bell-type inequalities (Bell, 1964; Leggett, 2003), making this a usefully innovative and plausible approach. The structure of the proton and neutron have been predicted within this Cordus theory, which is an important starting point for a nuclear model. In addition the theory reconceptualises the strong force as a synchronous interaction between the discrete forces emitted by particules (Dirk. J. Pons et al., 2013b). This proved to be useful, as it opened a solution path whereby the interaction between protons and neutrons could be anticipated. From this arose the prediction that the nucleons have a specific spatial assembly, which is characterised as a *nuclear polymer*. This has been sufficient to explain some simple nuclides, namely those of hydrogen and helium. The focus of the present paper is to expand the theory to explain a wider set of nuclides, namely hydrogen (H) to neon (Ne), some 140 nuclides in all. This is a challenging part of the nuclide landscape, because the changes between nuclides are abrupt. It is poorly served by existing models.

METHOD

The research question is an ontological one, as opposed to mathematical modelling, and benefits from application of a conceptual method. We applied a systems design method to infer the mechanics of a nuclear polymer that could explain the observed phenomena. In this case each nuclide, with its empirically observed properties, is a phenomenon. The design method involves creativity: envisaging various solutions and testing them in thought-experiments against known nuclide phenomena and empirical results, and iterating to find a set of mechanics that works. The fittest solution is that which can most parsimoniously explain as many phenomena as possible. For internal validity, we added the further requirement that the additional mechanics either had to be logically consistent with the lemmas of the prior Cordus theory, or had to rework those lemmas. This ensures a solution with wide-ranging coherence.

In hindsight, the biggest difficulty was finding a set of principles that explained *both* the stable and unstable nuclides. We found that it was relatively easy to create a candidate design for a given stable nuclide, but the real test was whether that design could also logically explain the known non-existence of certain nuclides and the trends for that series as a whole, while maintaining coherence with the designs for other series. Many of the elements have strange trends in their nuclides: unexpected drops or rises in stability; more/less nuclides than adjacent elements; missing nuclides; multiple stable nuclides – or only one. It took four iterations of the design processes to achieve a satisfactory solution. We only present the final result, not all the dead-ends.

4 RESULTS

The results identify a specific set of principles that when applied to the nuclear polymer are sufficient to explain the nuclides from hydrogen (H) to neon (Ne). Within this range, the theory is generally successful -there are exceptions- at explaining why any nuclide is stable, instable, or non-existent. The theory also explains why the drip lines are where they are, and gives a qualitative explanation of relative lifetimes of the nuclides and other trends.

4.1 FOUNDATIONAL PRINCIPLES FOR NUCLEAR STRUCTURE

The starting postulate of the Cordus theory is that all particles are really linear structures of finite length (hence *cordus*), have two reactive ends separated by a short distance (span), and from their two ends emit three-dimensional discrete forces that travel down flux lines (Cordus: *hyperfine fibril* or *hyff*) (Dirk. J. Pons et al., 2012). A fibril joins the reactive ends and is a persistent and dynamic structure but does not interact with matter. It provides instantaneous connectivity and synchronicity between reactive ends. The two reactive ends are energised in sequence at the de Broglie frequency. This structure is called a *particule*. The result is a non-local solution as the particule is affected by incoming discrete forces within the range of its reactive ends, as opposed to merely the fields at its nominal centre point. Thus locality fails but a principle of Wider Locality applies. For a fuller discussion see (Dirk. J. Pons et al., 2013b). [i]

Particules are differentiated by quantity and arrangement of their discrete forces. Previous papers provide the background to the structures of the proton and neutron, and develop a model of the strong force as negotiated synchronicity between discrete forces emitted by neighbouring particules. This was used to predict the physical structures of basic nuclear bonds, based on a geometric formulism of the discrete forces. Several different structures for proton-neutron assemblies were identified, including cis- and trans-phasic.[ii]

The Cordus theory predicts that such nucleons will have a tendency to assemble into a nuclear polymer comprising approximately orthogonal joints. This requirement arises from the orthogonality of the discrete forces and their handedness. The polymer is laid on the edges of a set of connected three-dimensional cubes. Two - and three-nucleon mechanics have been identified. The Cordus nuclear theory requires the network to be a generally closed loop of nucleons connected in series, with occasional cross bridges. The structure of those cross bridges has been identified: they are primarily neutrons, and there are specific requirements for the composition of the nucleons that make up the bridge-heads on each side. In turn this means that bridges are only possible in certain situations. Exceptions are the light elements, where open structures are permitted, terminated by protons but not by neutrons, as will be shown below.

The Cordus theory identifies the proposed structures of the proton and neutron. Key attributes that we need in building a nuclear theory are the identity of the nucleon (proton or neutron), its orientation in space, and the energisation phase of each particule. For this we devised a simplified representation, see Figure 1.

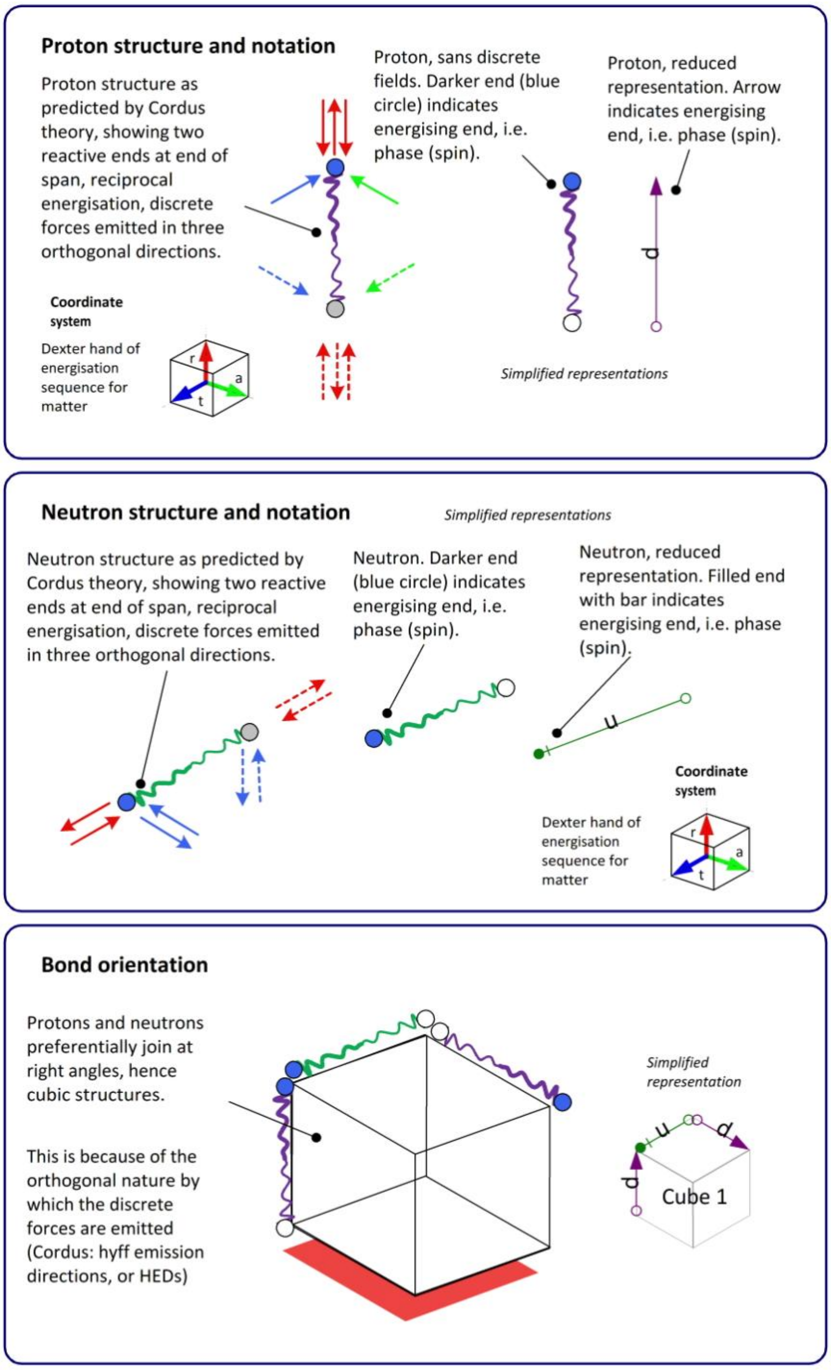


Figure 1: Simplified representation for nucleons.

Key features that differentiate this Cordus theory from other theories are: (a) the concept that the strong force is a synchronous interaction between discrete forces, as opposed to merely an exchange of bosons, (b) the concept that the synchronous interaction permits cis- and trans-phasic bonds, as opposed to merely the single interaction envisaged by other theories, (c) the concept of protons and neutrons having two reactive ends, energised in turn, as opposed to the 0-D point premise of QM. These concepts lead to the conclusion that protons and neutrons have multiple ways of bonding together.

4.2 COHERENT ASSEMBLIES AT THE NUCLEAR LEVEL

The Cordus theory has previously proposed that the synchronous interaction is the mechanism for coherent assembly of matter, and exclusively applies to such states. The electro-magneto-gravitational (EMG) interactions are proposed as the corresponding assembly mechanism for decoherent bodies. (This feature differentiates the Cordus theory from all other nuclear theories. It means that the electrostatic Coulomb interaction is nominally inoperative within the Cordus nucleus, whereas other nuclear theories assume the force is active). We now extend those principles to develop a theory for nuclear assembly.

COHERENCE IN THE NUCLEAR POLYMER

The Cordus synchronous interaction (strong force) provides that all particules that are assembled together using that interaction, will have the same frequency (or a harmonic thereof), and will be either in (cis) or out of (trans) phase with each other. Noting that particules are rod-like, and their reactive ends are energised in turn, the requirement for phase can also be expressed as requirement for the relative angular orientation of the two particules to be 0 or π radians. Hence the Cordus theory offers a physical interpretation of spin (Dirk. J. Pons et al., 2013b). Thus cis- and trans-phasic correspond to para- and ortho- spin states, and a physical interpretation is thereby provided for these two states, e.g. as in positronium.

Consequently the nuclear polymer is predicted to have one common frequency throughout, and each nucleon is in a cis or trans-phasic relationship with its neighbours. A nucleus is therefore proposed to be a coherent assembly. The same synchronous force that keeps it together also rips it apart if the frequencies cannot be maintained. Synchronicity is proposed to be a requirement for the nuclide to exist. If any member of the polymer cannot comply, then the polymer disassembles, i.e. the nuclide decays or cannot form.

POLYMER MORPHOLOGY AS KEY DETERMINANT OF STABILITY

We propose that the morphology of the polymer and the nature of the bonds are the primary determinants of stability/instability/non-viability of the nuclide concerned. The results identify a set of specific principles and rules that apply, i.e. it is possible to create a logically consistent mechanics, one that determines the shape of the polymer for each nuclide, and in turn that shape determines its stability. We present these principles first, in the form of lemmas or proposed statements of causality. Thereafter we present the proposed shape for each of the nuclides in this study. It should be noted that the lemmas and the shape models are different representations of a single underlying morphology, and are therefore intimately linked even though that might not seem the case on first inspection. Indeed these two outputs were developed concurrently as part of the design process, even if presented here serially.

STRAIN ACROSS THE POLYMER

With design revision four (the current version of the theory) it became apparent that a common theme could be identified in many of the lemmas. This is that *strain* across the nuclear polymer is a major factor in the viability and life of a nuclide. We anticipate two forms this strain takes. One is angular misalignment: while the nucleons may prefer to bond orthogonally to each other, the joint appears able to take some limited angular strain. The other is morphological: half-way round the loop (or any sub-loop), the polymer must be able to take a locus that will bring it back to its start and thereby close the loop with zero net torsional strain. We refer to this as the polymer needing to be *symmetrical.* This also means that the position of the bridge neutrons is crucial, since they are the means for determining the shapes of the subassemblies.

4.3 NUCLEAR ASSEMBLY MECHANICS: LEMMAS NP.6 FOR NUCLIDE STRUCTURES

The lemmas represent the proposed causality of the Cordus mechanics. It is not practical here to describe the design locus itself, i.e. how we came up with this particular set of mechanics. Nor can we here describe all the candidate solutions and dead ends, important as those are in eliminating unproductive parts of the solution space. Instead we simply present the lemmas as the outcomes. In the descriptions that follow, p refers to proton, n neutron, # cis-phasic joint between nucleons, x transphasic joint.

STABILITY/INSTABILITY/NON-VIABILITY

It turns out, according to this theory, that *stable* nuclides need not only to have a nuclear polymer that consists entirely of stable cis-phasic bonds, but also a viable shape of their nuclear polymer. Thus stability is proposed to be partially morphological. The first two lemmas detail the requirements.

Unstable nuclides, of which there are many, are explained as having unstable trans-phasic joints between nucleons, but still having a viable shape of polymer. Nuclear polymers made of these bonds will have a finite life. The reason trans-phasic bonds decay is, according to the Cordus theory, because outside perturbations from the fabric interfere with the synchronous interlock of the discrete forces. Trans-phasic bonds are much weaker at rejecting this interference, and are therefore the weakest link in the nuclear polymer.

The nuclides that do not exist or have very short lives (<1E-9s), which we categorise as *non-viable nuclides,* are explained as having either excessively long chains of trans-phasic joints, or cannot find a viable polymer shape with the number of protons and neutrons at their disposal, or both. In the table of nuclides these are seen as the limits of stability (drip lines), and as occasional gaps in the series. There may be viable nuclides each side of a gap, since adding another neutron sometimes makes a new shape available. Neither QCD nor the SEMF are able to explain these gaps, since they have no way to understand the interactions between individual nucleons.

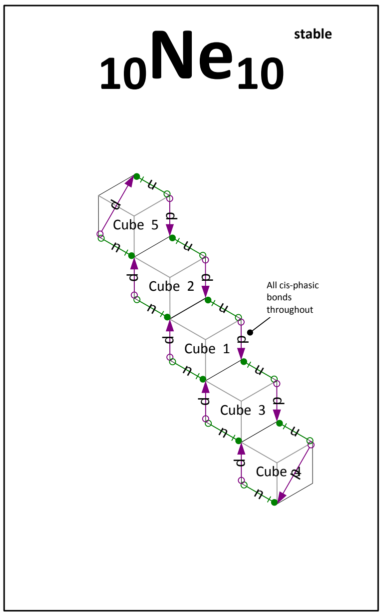
Please see Appendix A for the lemmas.

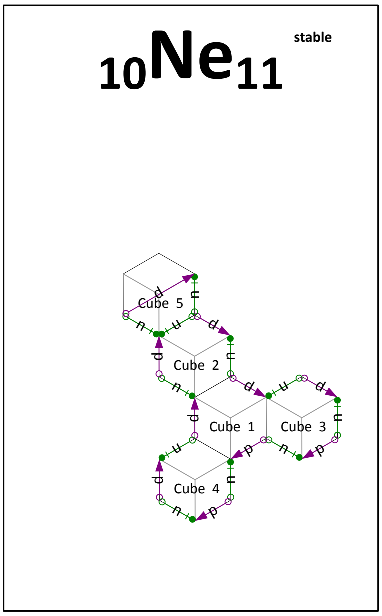
4.4 TABLE OF NUCLIDES H TO NE

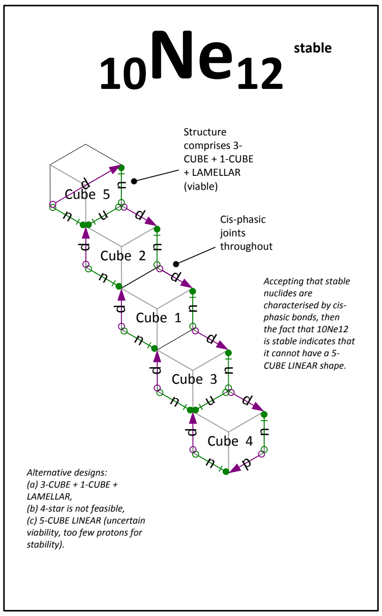
Application of the lemmas results in specific shapes of the polymers for the various nuclides. We start with the stable nuclides, and then move the unstable nuclides. Space precludes a detailed description of the shapes or an elaboration of how the lemmas apply to each case, but Appendix B has more details.

4.4.1 STABLE NUCLIDES

The stable nuclides from H to Ne are given in Figure 2. Each sub-figure presents the predicted internal structure of the nuclide.

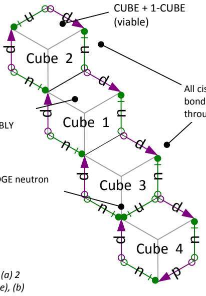






${}_{9}\mathrm{F}_{10}$ **stable**

The stability arises because all subassemblies are complete, and all bonds are cis-phasic.



Structure comprises 3-CUBE + 1-CUBE (viable)

All cis-phasic bonds throughout

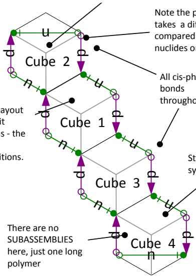
2-CUBE SUBASSEMBLY

BRIDGE neutron

Alternatives: (a) 2 Cube + 2 Cube), (b) 1 Cube + 3 Cube

${}_{8}\mathrm{O}_{8}$ **stable**

This nuclide is stable because it is possible to achieve a symmetrical layout with a simple looped polymer of cis-phasic joints. No bridge neutrons are necessary (they are optional, see 8O9).



Structure comprises 4-CUBES INCOMPLETE SYMMETRICAL (viable)

Note the polymner takes a different layout compared to the nuclides on each side

All cis-phasic bonds throughout

Note that this layout does not permit bridge neutrons - the protons are in unsuitable positions.

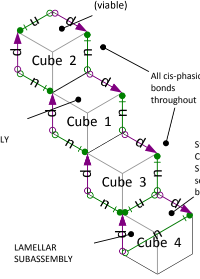
Structure is symmetrical

There are no SUBASSEMBLIES here, just one long polymer

${}_{8}\mathrm{O}_{9}$ **stable**

The stability arises because there is space for bridge neutrons, and all the subassemblies (single cube and a 3-CUBE) are complete.

This polymer makes a re-arrangement (cf 8O8 to get protons in suitable position to permit bridge neutrons



Structure comprises 3-CUBE + LAMELLAR (viable)

All cis-phasic bonds throughout

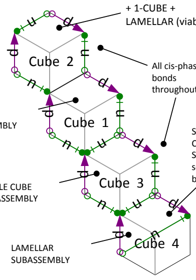
3-CUBE SUBASSEMBLY

Structure has COMPLETE SUBASSEMBLIES separated by bridge neutrons

LAMELLAR SUBASSEMBLY

${}_{8}\mathrm{O}_{10}$ **stable**

The stability arises because there is space for bridge neutrons, and all the subassemblies (lamellar, single cube and a 2-CUBE) are complete.



Structure comprises 2-CUBE + 1-CUBE + LAMELLAR (viable)

All cis-phasic bonds throughout

2-CUBE SUBASSEMBLY

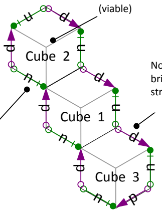
Structure has COMPLETE SUBASSEMBLIES separated by bridge neutrons

SINGLE CUBE SUBASSEMBLY

LAMELLAR SUBASSEMBLY

${}_{7}\mathrm{N}_{7}$ stable

The stability arises because the polymer is able to fill three cubes exactly.



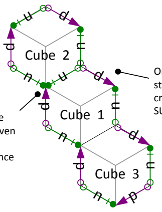
3-CUBE
This is a complete SUBASSEMBLY (viable)

No requirement for a bridge neutron in this structure.

All bonds are cis-phasic, hence stable

${}_{7}\mathrm{N}_{8}$ stable

The stability arises because there is space for a bridge neutron, and all the subassemblies (single cube and a 2-CUBE) are complete,



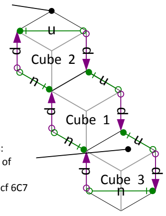
One bridge neutron is stable. This is because it creates COMPLETE SUBASSEMBLIES

All bonds are cis-phasic, even the bridge neutron, hence stable

${}_{6}C_{6}$

stable

This nuclide is stable with n=p=6 because there is a symmetrical structure that is available.



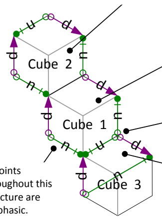
This assembly does not need a bridge neutron.

Polymer migrates: Location of protons changes cf 6C7

${}_{6}C_{7}$

stable

The stability arises because the neutron takes a bridge location and thereby partitions the structure into a stable pair of cubes (1 and 2), and a lamellar plate (3).



2-CUBE subassembly

All the SUBASSEMBLIES are COMPLETE

BRIDGE neutron partitions the structure into COMPLETE SUBASSEMBLIES

LAMELLAR SUBASSEMBLY

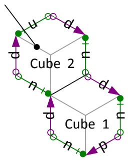
All joints throughout this structure are cis-phasic. Hence stable.

${}_{5}B_{5}$

(stable)

The structure neatly and completely fills two cubes, using only proton-to-neutron cis-phasic bonds (p#n), hence stability.

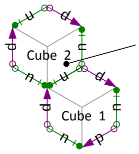
2-CUBE
Here at 5B5 is the first occurrence of the 2-CUBE stable subassembly. This does not need a bridge neutron.



${}_{5}B_{6}$

(stable)

A bridge neutron is an optional structure. The assembly is stable because the bridge creates two full cubes.

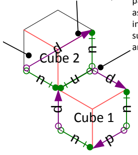


Neutron is positioned in a bridge location, which is stable.

${}_{4}Be_{5}$

(stable)

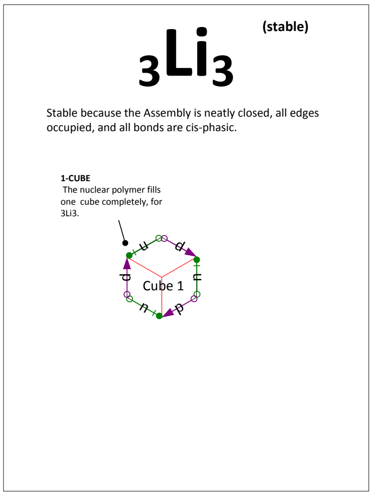
The structure is predicted to be a 4p 4n polymer loop, with a bridge neutron. The bridge neutron partitions the asymmetrical assembly into two individually complete sub-assemblies.



All the bonds in this entire assembly are cis-phasic (no trans-phasic), hence the stability.

This is a fully bonded new proton-neutron loop, not an accessory neutron-neutron loop

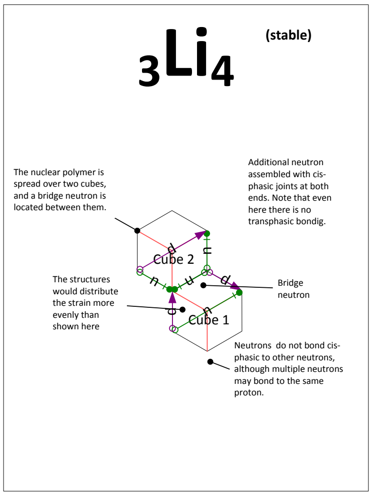
The bridge neutron partitions the asymmetrical assembly into two individually symmetrical sub-assemblies, a full cube and a lamellar plate.



$_{3}\mathrm{Li}_{3}$ **(stable)**

Stable because the Assembly is neatly closed, all edges occupied, and all bonds are cis-phasic.

1-CUBE
The nuclear polymer fills one cube completely, for 3Li3.



$_{3}\mathrm{Li}_{4}$ **(stable)**

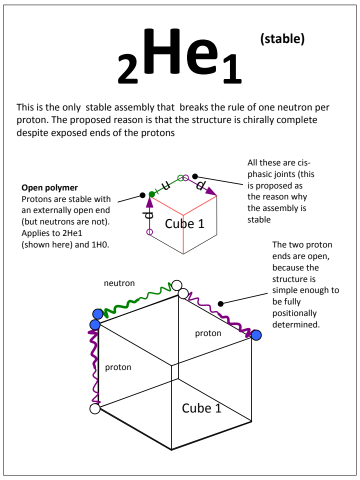
The nuclear polymer is spread over two cubes, and a bridge neutron is located between them.

Additional neutron assembled with cis-phasic joints at both ends. Note that even here there is no transphasic bondig.

The structures would distribute the strain more evenly than shown here

Bridge neutron

Neutrons do not bond cis-phasic to other neutrons, although multiple neutrons may bond to the same proton.



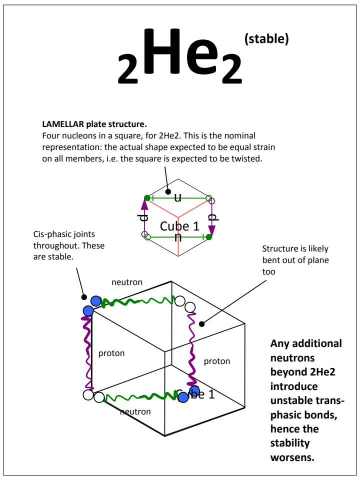
$_{2}\mathrm{He}_{1}$ **(stable)**

This is the only stable assembly that breaks the rule of one neutron per proton. The proposed reason is that the structure is chirally complete despite exposed ends of the protons

Open polymer
Protons are stable with an externally open end (but neutrons are not). Applies to 2He1 (shown here) and 1H0.

All these are cis-phasic joints (this is proposed as the reason why the assembly is stable

The two proton ends are open, because the structure is simple enough to be fully positionally determined.



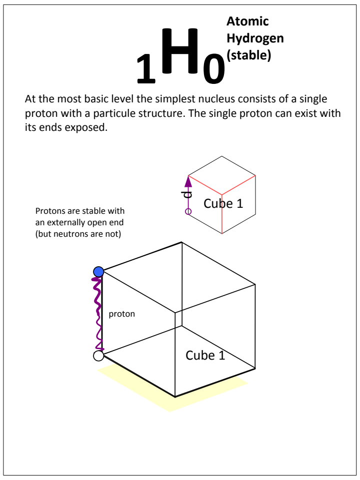
$_{2}\mathrm{He}_{2}$ **(stable)**

LAMELLAR plate structure.
Four nucleons in a square, for 2He2. This is the nominal representation: the actual shape expected to be equal strain on all members, i.e. the square is expected to be twisted.

Cis-phasic joints throughout. These are stable.

Structure is likely bent out of plane too

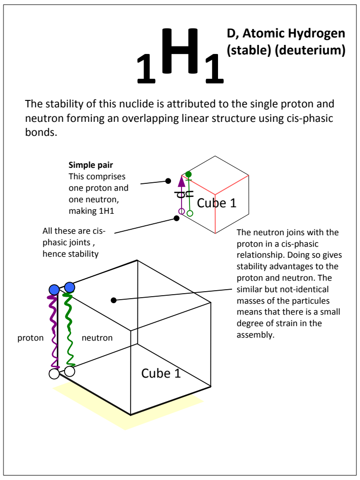
Any additional neutrons beyond 2He2 introduce unstable trans-phasic bonds, hence the stability worsens.



$_{1}\mathrm{H}_{0}$ **Atomic Hydrogen (stable)**

At the most basic level the simplest nucleus consists of a single proton with a particule structure. The single proton can exist with its ends exposed.

Protons are stable with an externally open end (but neutrons are not)



$_{1}\mathrm{H}_{1}$ **D, Atomic Hydrogen (stable) (deuterium)**

The stability of this nuclide is attributed to the single proton and neutron forming an overlapping linear structure using cis-phasic bonds.

Simple pair
This comprises one proton and one neutron, making 1H1

All these are cis-phasic joints , hence stability

The neutron joins with the proton in a cis-phasic relationship. Doing so gives stability advantages to the proton and neutron. The similar but not-identical masses of the particules means that there is a small degree of strain in the assembly.

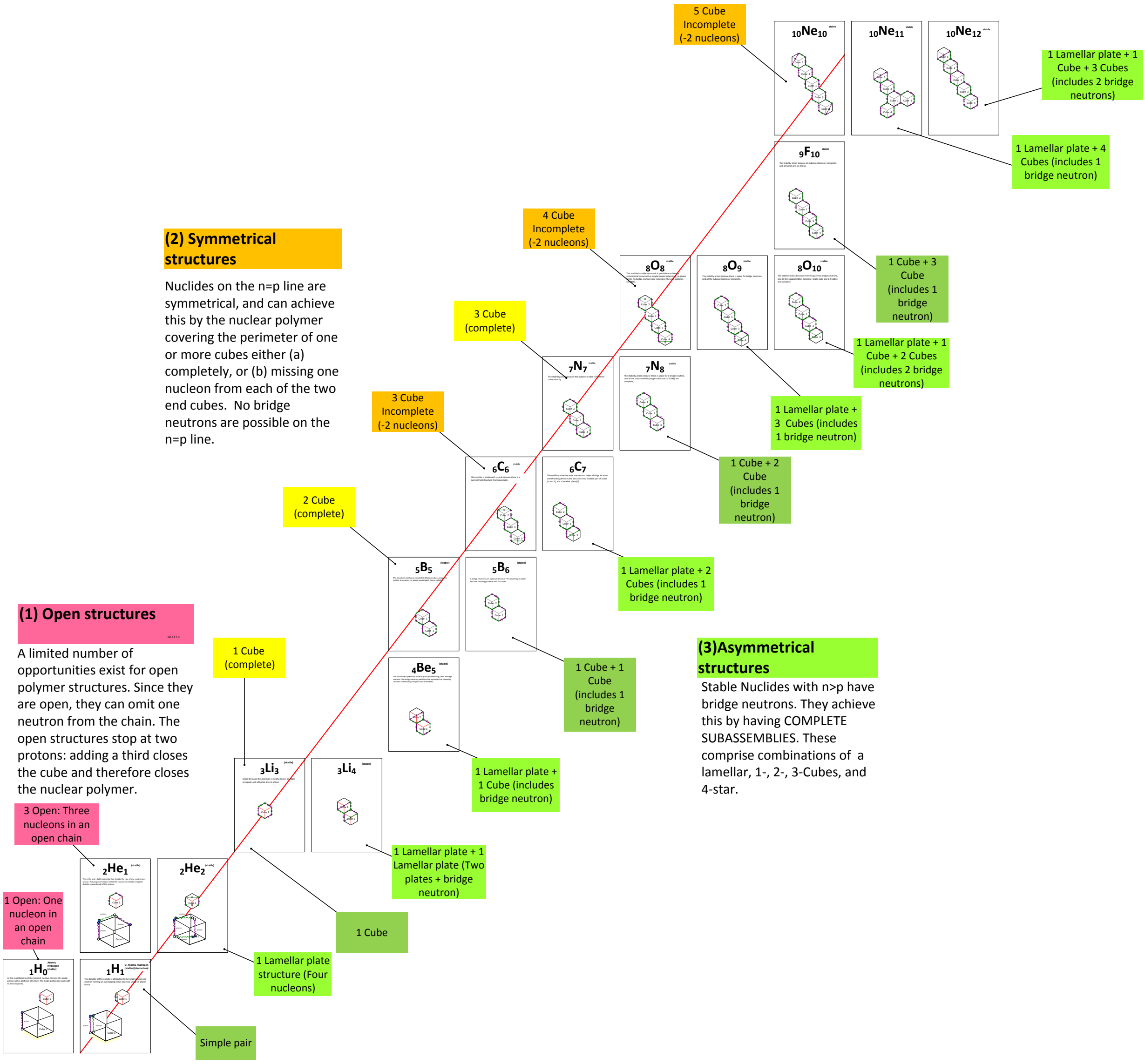
Figure 2: Stable nuclides from Hydrogen to Neon.

4.4.2 TRENDS FOR STABLE NUCLIDES

Having established the structures for the stable nuclides individually, we now turn to consider their trends.

STRUCTURAL TRENDS

The first is the structural trend, see Figure 3. The Cordus theory predicts a morphological progression from simple open structures (H and He), to symmetrical structures for those nuclides of Li to Ne that lie on the p=n line. The stable nuclides off the line (n>p) are predicted to have asymmetrical but complete subassemblies. Within each of these there is a finer progression which is reminiscent of the shell theories.



(1) Open structures

A limited number of opportunities exist for open polymer structures. Since they are open, they can omit one neutron from the chain. The open structures stop at two protons: adding a third closes the cube and therefore closes the nuclear polymer.

(2) Symmetrical structures

Nuclides on the n=p line are symmetrical, and can achieve this by the nuclear polymer covering the perimeter of one or more cubes either (a) completely, or (b) missing one nucleon from each of the two end cubes. No bridge neutrons are possible on the n=p line.

(3)Asymmetrical structures

Stable Nuclides with n>p have bridge neutrons. They achieve this by having COMPLETE SUBASSEMBLIES. These comprise combinations of a lamellar, 1-, 2-, 3-Cubes, and 4-star.

Figure 3: Structural trends for stable nuclides.

TREND FOR P=N FOR STABLE LIGHT NUCLIDES

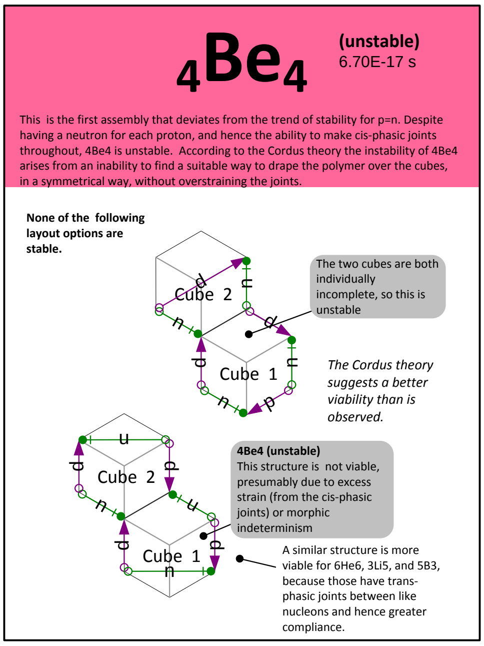
The trends whereby the stable nuclides deviate from the p=n line are also interesting, and the theory successfully explains these. The explanation is that for light elements the p=n nuclear polymer is stable, but heavier elements require bridge neutrons to divide the polymer into complete subassemblies. These additional neutrons cause the deviation from the main line. The greater the number of cubes used by the nuclear polymer, the greater the number of bridge positions potentially available. However not all bridge positions are permitted (since the subassemblies also need to be viable), so not all deviations are stable. Heavier elements have longer nuclear polymers and more bridge neutrons, and hence more stable nuclides.

ABERRATION OF NEUTRON-LIGHT NUCLIDES

This theory explains the two aberrations, 1H0 and 2He1 which are stable despite having p<n. The 1H0 nuclide is stable without any neutron, because the single proton is stable as an open structure. Likewise 2He1 is stable with only one neutron (rather than two), because it is an open series, as opposed to the generally closed nuclear polymer. The open structure is only available for the simplest nuclides, up to He. Three or more protons cannot be joined this way, as they close the polymer. Hence the theory correctly explains why the aberration occurs, and why it does not occur for Li or higher.

ABERRATION: 4BE4 AND 9F9 ARE UNSTABLE

In both 4Be4 and 9F9 there is no stable layout that meets the morphological rules. Specifically, for 4Be4 the issue is a lack of viability for a 2-linear symmetrical incomplete assembly, see Figure 4. For 9F9 the aberration arises because there is no stable layout with only 4-cubes, see Figure 5. None of the other H-Ne nuclides have these problems of finding a suitable layout. Note that in both 4Be4 and 9F9 the polymers meet the other stability requirement, which is to comprise entirely cis-phasic joints.



$_4Be_4$ **(unstable)** 6.70E-17 s

This is the first assembly that deviates from the trend of stability for p=n. Despite having a neutron for each proton, and hence the ability to make cis-phasic joints throughout, 4Be4 is unstable. According to the Cordus theory the instability of 4Be4 arises from an inability to find a suitable way to drape the polymer over the cubes, in a symmetrical way, without overstraining the joints.

None of the following layout options are stable.

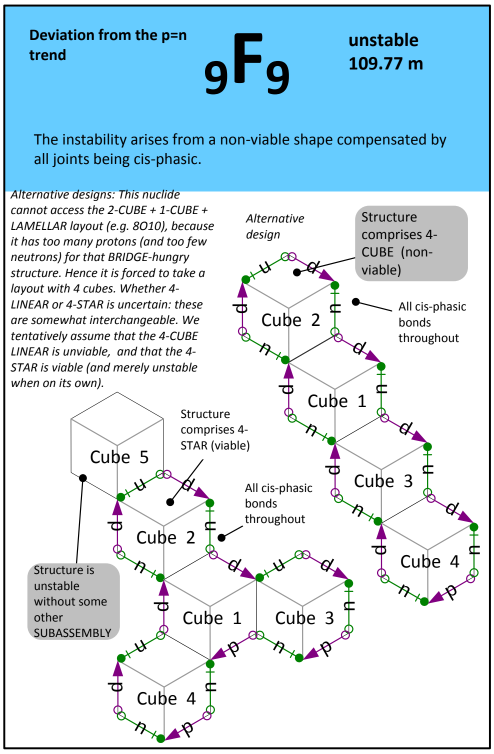
The two cubes are both individually incomplete, so this is unstable

The Cordus theory suggests a better viability than is observed.

4Be4 (unstable) This structure is not viable, presumably due to excess strain (from the cis-phasic joints) or morphic indeterminism

A similar structure is more viable for 6He6, 3Li5, and 5B3, because those have trans-phasic joints between like nucleons and hence greater compliance.

Figure 4: Explanation for the non-viability of 4Be4.



Deviation from the p=n trend $_9F_9$ **unstable 109.77 m**

The instability arises from a non-viable shape compensated by all joints being cis-phasic.

Alternative designs: This nuclide cannot access the 2-CUBE + 1-CUBE + LAMELLAR layout (e.g. 8O10), because it has too many protons (and too few neutrons) for that BRIDGE-hungry structure. Hence it is forced to take a layout with 4 cubes. Whether 4-LINEAR or 4-STAR is uncertain: these are somewhat interchangeable. We tentatively assume that the 4-CUBE LINEAR is unviable, and that the 4-STAR is viable (and merely unstable when on its own).

Alternative design

Structure comprises 4-CUBE (non-viable)

All cis-phasic bonds throughout

Structure comprises 4-STAR (viable)

All cis-phasic bonds throughout

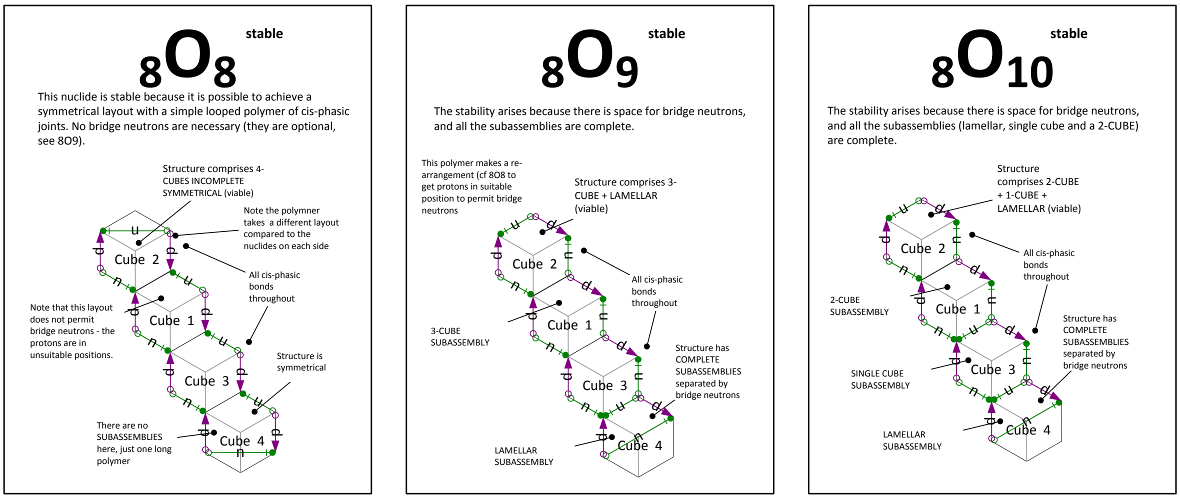
Structure is unstable without some other SUBASSEMBLY

Figure 5: Explanation for the non-viability of 9F9.

STABLE ISOTOPES (HORIZONTAL RUNS)

Certain elements have multiple stable isotopes, i.e. a horizontal run, the first case in point being 8O8, 8O9, 8O10, see Figure 6. These are puzzling trends that are not explained by other theories. In the Cordus theory the explanation arises naturally from consideration of the polymer filling rules. Specifically, these runs are due to the structure having the ability to accept additional bridge neutrons. This is achieved by changing the shape of the polymer as more neutrons are added.

In understanding this effect it is important to note that the additional bridge neutrons are placed into cis-phasic bonding situations, hence the first of the two stability requirements is met. The second stability requirement is for a viable shape, which these isotopes provide. Thus 8O8 is a symmetrical incomplete structure with cis-phasic bonds throughout, hence stable. Adding a neutron to make 8O9 changes the assembly to a 3-CUBE + LAMELLAR (viable), and retains cis-phasic bonds throughout, hence stable. Likewise the change to 8O10 (2-CUBE + 1-CUBE + LAMELLAR) is also stable. The run of stable isotopes stops when there are no further stable bridge positions available, which is a function of the number of cubes. This also explains why lighter elements like Oxygen (which have fewer cubes) have fewer stable isotopes (shorter runs). These runs of stable isotopes are a strong feature of the larger table of nuclides, and the basic principles described here explain why they occur, and also why they only start at Oxygen. The Cordus nuclear theory also explains the vertical isotones as complementary to the horizontal runs of stable isotopes, and these are explained next.


$_8O_8$ stable

This nuclide is stable because it is possible to achieve a symmetrical layout with a simple looped polymer of cis-phasic joints. No bridge neutrons are necessary (they are optional, see 8O9).

Structure comprises 4-CUBES INCOMPLETE SYMMETRICAL (viable)

Note the polymner takes a different layout compared to the nuclides on each side

All cis-phasic bonds throughout

Note that this layout does not permit bridge neutrons - the protons are in unsuitable positions.

Structure is symmetrical

There are no SUBASSEMBLIES here, just one long polymer

$_8O_9$ stable

The stability arises because there is space for bridge neutrons, and all the subassemblies are complete.

This polymer makes a re-arrangement (cf 8O8 to get protons in suitable position to permit bridge neutrons

Structure comprises 3-CUBE + LAMELLAR (viable)

All cis-phasic bonds throughout

3-CUBE SUBASSEMBLY

Structure has COMPLETE SUBASSEMBLIES separated by bridge neutrons

LAMELLAR SUBASSEMBLY

$_8O_{10}$ stable

The stability arises because there is space for bridge neutrons, and all the subassemblies (lamellar, single cube and a 2-CUBE) are complete.

Structure comprises 2-CUBE + 1-CUBE + LAMELLAR (viable)

All cis-phasic bonds throughout

2-CUBE SUBASSEMBLY

Structure has COMPLETE SUBASSEMBLIES separated by bridge neutrons

SINGLE CUBE SUBASSEMBLY

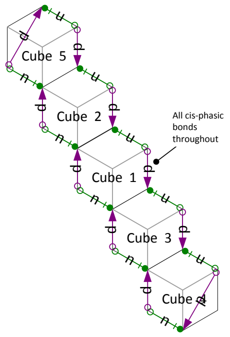
LAMELLAR SUBASSEMBLY

Figure 6: The horizontal runs, for example the stable oxygen nuclides, are proposed to have a morphological origin.

Stable Isotones: Vertical Ladder

The stable isotones (vertical ladders) are nuclides with the same neutron count, but different protons. The first example in the table of nuclides is 8O10, 9F10, 10Ne10, see Figure 7.

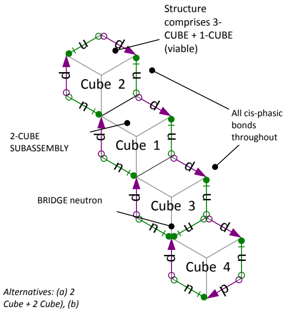
$_{10}$Ne$_{10}$ **stable**



All cis-phasic bonds throughout

$_{9}$F$_{10}$ **stable**

The stability arises because all subassemblies are complete, and all bonds are cis-phasic.



Structure comprises 3-CUBE + 1-CUBE (viable)

All cis-phasic bonds throughout

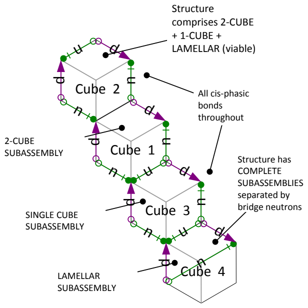
2-CUBE SUBASSEMBLY

BRIDGE neutron

Alternatives: (a) 2 Cube + 2 Cube), (b) 1 Cube + 3 Cube

$_{8}$O$_{10}$ **stable**

The stability arises because there is space for bridge neutrons, and all the subassemblies (lamellar, single cube and a 2-CUBE) are complete.



Structure comprises 2-CUBE + 1-CUBE + LAMELLAR (viable)

All cis-phasic bonds throughout

2-CUBE SUBASSEMBLY

Structure has COMPLETE SUBASSEMBLIES separated by bridge neutrons

SINGLE CUBE SUBASSEMBLY

LAMELLAR SUBASSEMBLY

Figure 7: Stable isotones (vertical ladders) of nuclides. These have the same number of neutrons (10 in this case) but different protons, and are all stable.

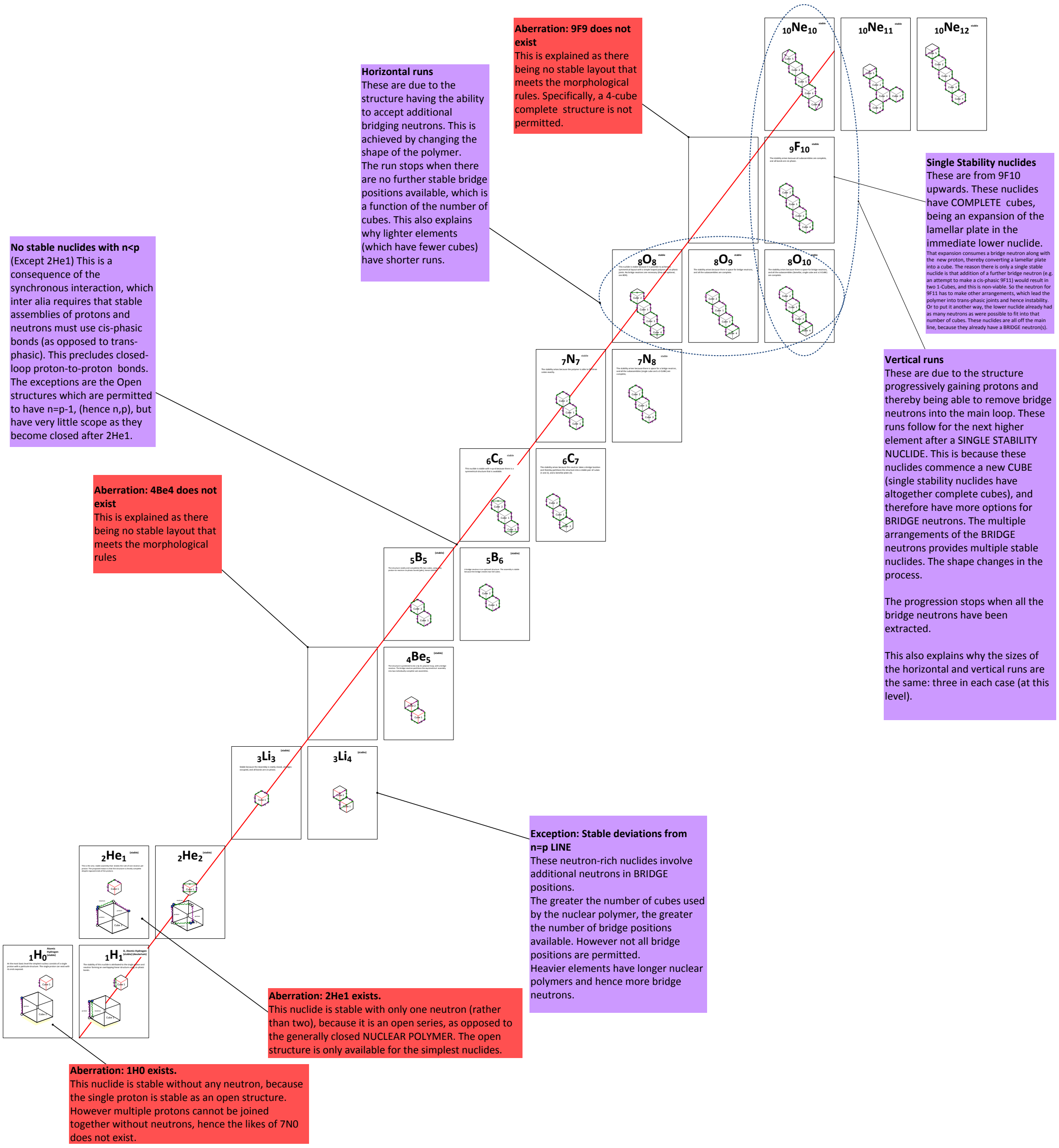
The Cordus theory explains these stable isotones (ladders) as due to the structure progressively gaining protons and thereby being able to remove bridge neutrons into the main loop. The lower rung of the ladder, 8O10 in this case, is packed with as many bridge neutrons as is feasible, which is two bridges (hence 2-CUBE + 1-CUBE + LAMELLAR for 8O10). Importantly, the smallest subassembly is a lamellar. This is significant because adding a proton to make 9F10 allows the polymer to add the proton and one bridge neutron to convert the lamellar to a 1-cube. In this way it reaches a viable layout, and retains cis-phasic joints, hence stability.

In this case 9F10 is what we term a *Single-Stability nuclide*: there is only one stable nuclide for this element. This is characteristic of the vertical ladders generally. These single-stability nuclides arise from 9F10 upwards. These nuclides have assemblies comprising complete cubes, this being a consequence of the expansion of the lamellar plate in the immediate lower nuclide. The reason there is only a single stable nuclide is that the both the lower (9F8) and higher (9F11) nuclides are unstable. In both cases the reasons are morphological. For 9F8 the reason is the 4-STAR is unstable when on its own (see earlier figure). For 9F11 adding a bridge neutron in an attempt to make a cis-phasic 9F11 would result in two 1-Cubes, and this is non-viable. Another characteristic of the single-stability nuclides is that they are off the p=n line, which is explained as their all having a bridge neutron.

The top rung of this ladder involves an additional proton to make 10Ne10. The availability of this proton permits the polymer to reallocate the bridge neutron into the main loop, thereby creating a 5-cube symmetrical incomplete layout with cis-phasic bonds, hence stable. Importantly, this is the last bridge neutron to be extracted, and this causes the vertical ladder to stop here (hence 11Si10 is not stable).

The insertion of bridge neutrons into the polymer to create the horizontal runs, and their extraction for the vertical ladders also handily explains why the sizes of the horizontal and vertical runs are the same: three in each case (at this level). Heavier elements have more cubes available, and hence longer runs and ladders.

A summary of these trends is shown in Figure 8.



Aberration: 9F9 does not exist
This is explained as there being no stable layout that meets the morphological rules. Specifically, a 4-cube complete structure is not permitted.

Horizontal runs
These are due to the structure having the ability to accept additional bridging neutrons. This is achieved by changing the shape of the polymer. The run stops when there are no further stable bridge positions available, which is a function of the number of cubes. This also explains why lighter elements (which have fewer cubes) have shorter runs.

Single Stability nuclides
These are from 9F10 upwards. These nuclides have COMPLETE cubes, being an expansion of the lamellar plate in the immediate lower nuclide.
That expansion consumes a bridge neutron along with the new proton, thereby converting a lamellar plate into a cube. The reason there is only a single stable nuclide is that addition of a further bridge neutron (e.g. an attempt to make a cis-phasic 9F11) would result in two 1-Cubes, and this is non-viable. So the neutron for 9F11 has to make other arrangements, which lead the polymer into trans-phasic joints and hence instability. Or to put it another way, the lower nuclide already had as many neutrons as were possible to fit into that number of cubes. These nuclides are all off the main line, because they already have a BRIDGE neutron(s).

No stable nuclides with n<p
(Except 2He1) This is a consequence of the synchronous interaction, which inter alia requires that stable assemblies of protons and neutrons must use cis-phasic bonds (as opposed to trans-phasic). This precludes closed-loop proton-to-proton bonds. The exceptions are the Open structures which are permitted to have n=p-1, (hence n,p), but have very little scope as they become closed after 2He1.

Vertical runs
These are due to the structure progressively gaining protons and thereby being able to remove bridge neutrons into the main loop. These runs follow for the next higher element after a SINGLE STABILITY NUCLIDE. This is because these nuclides commence a new CUBE (single stability nuclides have altogether complete cubes), and therefore have more options for BRIDGE neutrons. The multiple arrangements of the BRIDGE neutrons provides multiple stable nuclides. The shape changes in the process.

The progression stops when all the bridge neutrons have been extracted.

This also explains why the sizes of the horizontal and vertical runs are the same: three in each case (at this level).

Aberration: 4Be4 does not exist
This is explained as there being no stable layout that meets the morphological rules

Exception: Stable deviations from n=p LINE
These neutron-rich nuclides involve additional neutrons in BRIDGE positions.
The greater the number of cubes used by the nuclear polymer, the greater the number of bridge positions available. However not all bridge positions are permitted.
Heavier elements have longer nuclear polymers and hence more bridge neutrons.

Aberration: 2He1 exists.
This nuclide is stable with only one neutron (rather than two), because it is an open series, as opposed to the generally closed NUCLEAR POLYMER. The open structure is only available for the simplest nuclides.

Aberration: 1H0 exists.
This nuclide is stable without any neutron, because the single proton is stable as an open structure. However multiple protons cannot be joined together without neutrons, hence the likes of 7N0 does not exist.

Figure 8: Explanations for the nuclides that deviate from the p=n line.

Having explained the stable nuclides and their trends, we now turn to the unstable nuclides.

4.4.3 UNSTABLE AND NON-VIABLE NUCLIDES

The Cordus nuclear theory predicts layouts for all the unstable nuclides from H to Ne, see Figure 9. For each it provides a qualitative explanation of the relative trends in life. There are very many unstable nuclides, and a full description is beyond the present paper, though Appendix B (online only) contains a more detailed representation of the nuclides with explanatory text for each. (The neutron-nuclides are also included, but these are more of a curiosity.)

RELATIVE STABILITY IS EXPLAINED

The theory successfully explains relative stability: why any one nuclide is more/less stable than its neighbour. Generally the explanation is that less stable nuclides have longer chains of plain protons (or neutrons as the case may be). The irregular changes in relative stability across a series are successfully explained with the Cordus theory. Other theories, including binding energy models, do not accommodate these changes. It has been noted before that binding energy is an unreliable predictor of stability, and the Cordus theory starts to show why. The explanation is that the number of trans-phasic bonds, which is zero medially (at or near p=n), tends to increase distally across a series. It so happens that binding energy also decreases distally, though it does so smoothly (for reasons not described here). It is the number of trans-phasic bonds, and the viability of the shape, that determine nuclide life, and binding energy emerges as merely a proxy or secondary variable.

GAPS AND NON-VIABLE NUCLIDES ARE EXPLAINED

Also, the Cordus theory can explain all the non-viable nuclides -those gaps in the series, and the limits of stability- in terms of morphology. The gaps arise because there are no viable shapes accessible for a polymer with that specific number of protons and neutrons. Towards the distal extremes of the series, the number of trans-phasic bonds increases, which also contributes to non-viability (see Lemma NP.6.8).

LIMITS OF STABILITY ARE EXPLAINED

The limits of stability are also easily explained, i.e. why the series start and stop where they do. The start constraints, i.e. the limits to the proton-rich nuclides, are primarily *occupancy* (Lemma NP.6.7) specifically the need for a neutron per cube, and limits on *proton density* (Lemma NP.6.8).

The end constraints, i.e. the upper limits to the neutron-rich nuclides, are not so much the non-availability of a viable layout, as the *inaccessibility* of such layouts due to the need for *occupancy* (Lemma NP.6.7) and *proton continuity* (Lemma NP.6.9). At the limit, the element does not have enough protons to service additional cubes, and therefore cannot access such layouts.

The theory suggests that the limits of stability for neutron-rich nuclides could in some cases be slightly higher than empirically observed. For example the Boron series is generally understood to stop at 5B16, whereas morphological considerations suggests it stops at 5B17. However neither of these are viable nuclides anyway, so it does not matter much.

In this theory the lower and upper limits of stability are shown to be determined by polymer considerations for each element *independently*. What happens for one element need not be similar to other elements, even though there is a general trend of heavier elements having more cubes and hence increased limits. Therefore the Cordus theory suggests we should not expect to find the limits for one element correlated to those of its immediate neighbours. Indeed this is exactly what the empirical evidence shows: the limits margins are irregular. Consequently we reject the concept of drip 'lines': there is neither empirical evidence nor theoretical support for the idea that the stability limits for multiple nuclides are connected by contour 'lines'. The 'line' idea is an artefact of the SEMF model and its propensity to create smooth gradients of binding energy.

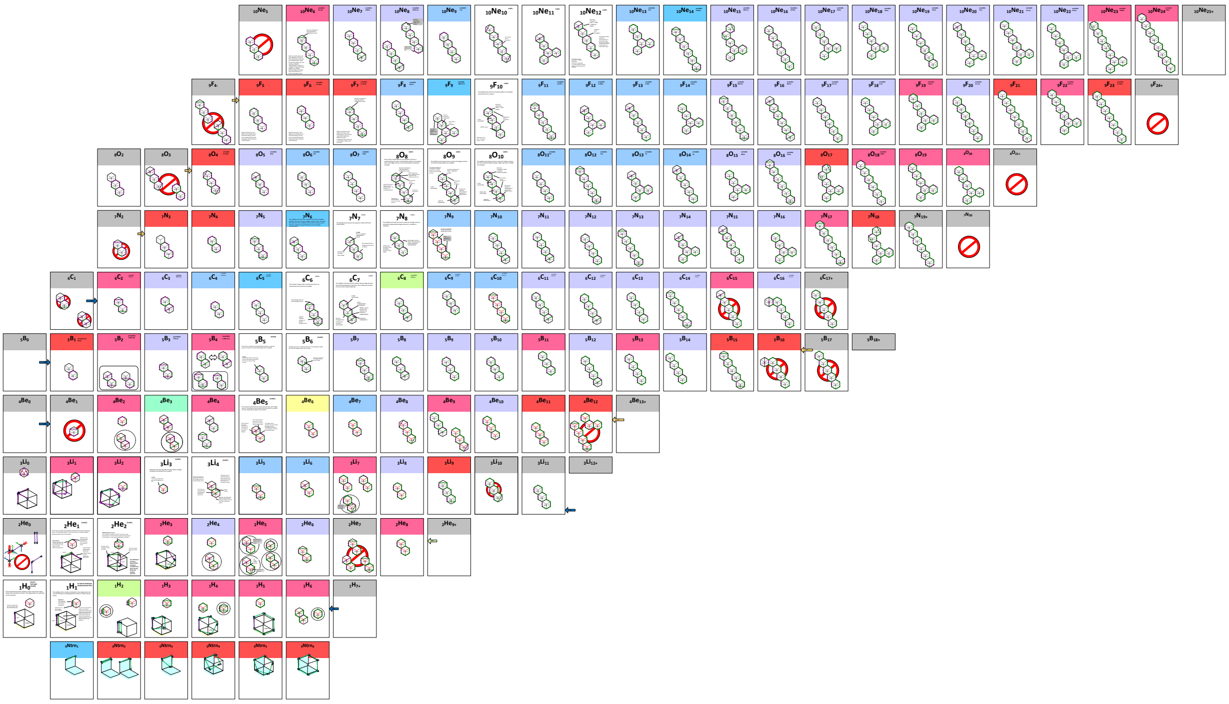


Figure 9: Predicted shapes of all the nuclides, stable and unstable, from Hydrogen to Neon, from the Cordus theory. See Appendix B (online) for higher resolution image.

Generally the Cordus nuclear theory shows excellent explanatory power for the life of the nuclides, in that it correctly differentiates between the stable/unstable/non-viable nuclides. It correctly identifies the limits of stability on both the proton and neutron rich ends of the series. It also explains the trends in stability, including the sudden changes (positive and negative) within the series. The latter have been difficult for other theories to explain.

EXCEPTIONS

There are some exceptions, though none of these is a major problem since there are no situations where the Cordus theory is totally at odds with the empirical life data. Minor discrepancies are observed for 4Be4, 4Be9, 4Be11, 5B4, 8O4, 8O17, 9F7, 10Ne6, and 9F19, where the Cordus theory suggests a slightly better viability than is observed. These are all nuclides that are highly unstable (<1E-9s) or non-viable, so this is a reflection on the difficulty of characterising the limits of stability. All the stable and merely instable nuclides are readily accommodated within the Cordus theory.

There is only one situation where the Cordus theory predicts a worse viability than is observed, and that is 8O20. The Cordus theory suggests this nuclide should not exist at all, whereas the empirical evidence is for a barely viable nuclide with life <100ns. This difference is perhaps unimportant, given the general indistinctness between *non-viable* and *non-existent.*

It is noteworthy and curious that the Cordus nuclear theory generally predicts only *one* unique shape for each nuclide. This was not something we deliberately set out to achieve, rather it is an emergent characteristic of the lemmas. It is curious because it suggests that the nuclear shape is constant, rather than changing, for any one nuclide. This characteristic arises since the progressive construction of the polymer is fundamentally a morphological process, which naturally embodies a progression of unique shapes under the given rules. It is possible that morphological uniqueness is another criteria for viability (along with cis-phasic joints and a viable layout). Thus it may be that where the mechanics permitted multiple shapes, there the nuclide would be unstable. However we do not have many data points to be certain on this. The only case encountered is 9F21, but that is capable of other explanations too.

6 DISCUSSION

WHAT HAS BEEN ACHIEVED?

This work makes several novel intellectual contributions. The first is the ontological contribution of showing causality from the strong force (Cordus: *synchronous interaction*) all the way up to nuclear structure. This has not previously been achieved by any other nuclear theory.

The second contribution is the provision of a theory with sufficient explanatory power to explain the lateral phenomena in the nuclide series. Specifically it is capable of explaining why any nuclide is stable, unstable, non-viable or non-existent. It can explain why there are only one stable nuclide, or two or three as the case may be. Related to that, the theory also explains the horizontal runs (multiple stable nuclides for one element). The theory can explain relative stability (lateral trends with one nuclide series), including the anomalous progressions (i.e. those situations where one nuclide is unexpectedly much more or less stable than its neighbouring nuclides). The theory also explains why the limits of stability are where they are, as opposed to somewhere else.

The third contribution is that the theory explains the vertical integration between the nuclides. Specifically it explains why stability for the lighter elements tend to be at p=n, and why the deviation from the p=n line occurs for the heavier elements (neutrons are placed in bridge positions). The theory also explains the aberrations: why 1H0 and 2He1 are stable with low neutron counts. The instability of 4Be4 and 9F9 are also explained. It also explains the vertical ladders whereby nuclides of a common neutron count are stable (the reasons are morphological). Related to that, the theory explains the connectedness between those vertical ladders, the horizontal runs, and the single-stability nuclides.

The fourth contribution is the provision of an explicit nuclear mechanics, in the form of a set of lemmas, by which the structures of all these nuclides may be generated. We are not claiming these lemmas are the end of the matter, but we do present them as a workable starting theory of causality for nuclear mechanics.

The sixth contribution is methodological, in that we have shown that application of the design method is capable of generating conceptual theories with high explanatory power. An associated contribution is the demonstration that non-local hidden-variable designs have great potential. This is important as hidden-variable designs have generally been treated contemptuously by orthodox physics.

There is a seventh contribution, though it will not be apparent in this paper in isolation, which is the construction of a wider theory with large-scale coherence and explanatory power. The Cordus theory now has the capability to explain many phenomena including wave-particle duality, entanglement, optical laws (Dirk. J. Pons et al., 2012), electro-magnetic-gravitation forces, the strong force (Dirk. J. Pons et al., 2013b), time (D. J. Pons, A. Pons, D., & A. Pons, J., 2013a), the horizon aspects of cosmology (Dirk. John. Pons & Pons, 2013), and now the nuclides. The important point is that the theory has a logical consistency throughout. That it has been possible to create a theory for the nuclides, without breaking any of the lemmas for the other parts of the theory, is evidence for conceptual coherence.

IMPLICATIONS

The Cordus theory offers a new physics for nuclear mechanics. This involves several new concepts:

- a NLHV design whereby *particules* have physical structures, as opposed to the QM construct of zero-dimensional points;
- a *synchronous interaction*, as opposed to the gluons and strong force of QCD;
- multiple types of synchronous bond (*cis- and trans-phasic*), as opposed to the single strong force of QM;
- a *nuclear polymer*, being a network of interlinked nucleons, as opposed to the liquid drop and shell models of the like of the SEMF;
- a *morphological nuclear mechanics* describing the spatial arrangements of the polymer, with a resulting explanation of the table of nuclides.

Each of these concepts is novel, and entirely different to the existing theories. The Cordus theory is not an interpretation of QM or any existing theory, but a re-conceptualisation of foundational physics. If the theory is correct then the implications are correspondingly radical. The Cordus theory would subsume QM, since the probabilistic wave-function of QM can be interpreted as a rough statistical approximation of a deeper Cordus particule behaviour, and all QM's quantitative machinery can be left intact. However the Cordus theory rejects QM's bosons as force carriers, and likewise rejects QCD's gluons. At some level we would expect the Cordus theory to be complementary to the SEMF and liquid drop models, because those are models for the geometric packing of the nucleons. However the point of difference for the Cordus theory is that is offers a design for the *inside* of the nucleus and the bonds between its components, whereas existing models stop at the aggregate level. Therefore the Cordus theory has the potential to provide a conceptual discontinuity in the development of fundamental physics.

LIMITATIONS

The work has its limitations. The first is that of scope: the work is currently limited to the nuclides from Hydrogen to Neon. This is simply a workload constraint, and there is every reason to believe that the principles developed here are applicable, perhaps with modification, to heavier elements.

The second limitation is that the work is primarily conceptual, and its mechanics are expressed qualitatively. This is not a deficiency, though it might seem that way to those more used to seeing physics expressed mathematically. Rather it is a consequence of an objective which was to reconceptualise fundamental physics. For this objective, it is more valuable to have a framework that is logically consistent across a very wide range of phenomena, i.e. coherent and with explanatory power, than a quantitative solution for a narrowly defined area. The mathematical formalism is a detail that can be added later. Consequently, while we recognise the need to eventually have the concept developed into a more quantitative detailed form, we temporarily leave that for future work.

There are no serious limitations in the explanations provided by this Cordus theory for the nuclides from H to Ne. All the nuclides can be explained. For a small minority of the highly unstable/non-viable nuclides the explanations are weaker than ideal (details given above) but this does not affect the overall theory.

The theory makes numerous falsifiable claims for nuclear structure: one per nuclide.

IMPLICATIONS FOR FUTURE RESEARCH

The theory has been built on known empirical data for the lifetimes and viability of the nuclides. There are other characteristics of the nuclides, and these could be considered in future refinements of the theory: binding energy, charge radius, proton and neutron separation energies. The mechanics developed here reflect the first attempt at a theory, and it is to be expected that the theory will change as these other phenomena are included. Other areas for future research include development of a theory for polymer strain, and extension of the theory to heavier elements. While it is difficult to validate a conceptual theory, the greater the explanatory power the fitter the theory. The future research developments could help determine that fitness. An ultimate research question would be to make quantitative predictions from first principles, e.g. of the lifetime of a given nuclide.

7 CONCLUSIONS

One of the deep gaps in fundamental physics is how to explain the causality from the strong nuclear force to nuclear structures. This has not previously been achievable with existing theories. A complementary problem has been that existing models of nuclear structure treat the protons and neutrons collectively, and are unable to describe the detailed interaction of the nucleons. Consequently there has been a lack of theoretical explanations for the nuclides, their trends in stability, instability, and non-viability. The present work addresses this problem, by developing a theory that explains the nuclides from the synchronous interaction (strong force) upwards.

The basis of the Cordus nuclear theory is that the nucleus consists of a nuclear polymer, which in turn comprises proton and neutron particules (these have internal structure and are not zero-dimensional points) bonded by the synchronous interaction. Unlike conventional representations of the strong force, the Cordus synchronous interaction is capable of two types of bond, cis- and trans-phasic. This becomes an important determinant of nuclear stability, in that stable nuclides are required by this theory to have entirely cis-phasic bonds between nucleons. Three-particle physics are accommodated, in the form of bridge neutrons across the nuclear polymer. The other requirement for stability is that the nuclear polymer be able to take a viable layout. These layouts are proposed to be fundamentally morphological, in that the polymer is required to be draped over a set of interconnected lamellar and cubic shapes. Instability arises when trans-phasic bonds are necessary. Non-viable and extremely short-lived nuclides arise when viable layouts are inaccessible to the polymer: the requirements for these are identified.

The Cordus nuclear theory is expressed as an explicit nuclear mechanics, in the form of a set of lemmas, by which the structures of the nuclides may be generated. The resulting theory successfully explains, for all nuclides from Hydrogen to Neon, why any nuclide is stable, unstable, non-viable or non-existent. It explains why some elements have multiple nuclides, and others only one. The theory also explains the deviations from the p=n line, why 1H0 and 2He1 are stable with low neutron counts, why 4Be4 and 9F9 are unstable, and why heavier elements require more neutrons than protons for stability. It explains relative stability (lateral trends with one nuclide series), including the anomalous progressions (i.e. those situations where one nuclide is unexpectedly much more or less stable than its neighbouring nuclides). The theory also explains why the limits of stability are where they are. It explains the patterns of stability in the table of nuclides, such as the horizontal runs and vertical ladders.

The explanatory power is excellent for the light nuclides, where existing approaches based on bonding energy traditionally struggle. The principles are expected to be generally applicable to the nuclides of heavier elements.

Combined with applications of the Cordus theory to explain other areas, the work shows that non-local hidden-variable designs have potential in providing solutions with high explanatory power and wide-ranging logical consistency for difficult problems in fundamental physics.

A Appendix: Nuclear polymer lemmas

NP.6.1 A stable nuclear assembly must have cis-phasic bonds throughout.

6.1.1 It may have bridge neutrons. See Figure A1.

6.1.2 It may not have trans-phasic bonds, and this means it cannot have chains of solely protons or neutrons.

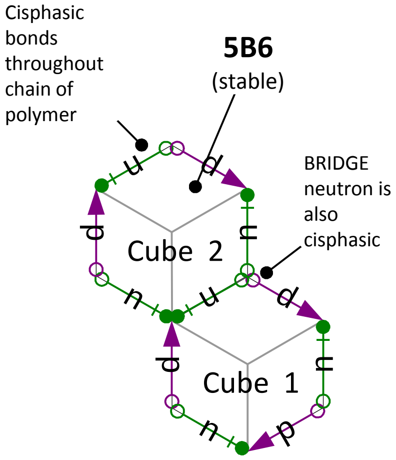


Figure A1: A stable assembly has cis-phasic bonds throughout.

NP.6.2 A viable nuclide (i.e. stable or unstable) must have a suitable layout of its polymer. Viable layouts are OPEN layouts, or SYMMETRICAL, or comprise COMPLETE SUBASSEMBLIES.

6.2.1 Open layouts are viable.

6.2.1.1 A simple pair of nucleons is viable, see Figure A2.

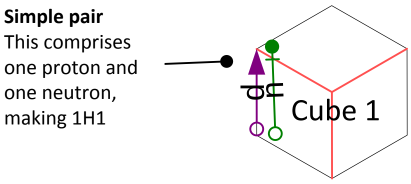
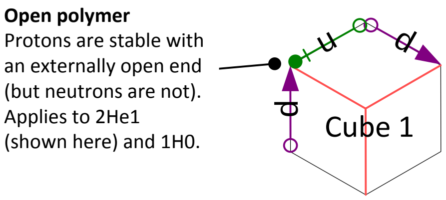


Figure A2: Simple pair of nucleons

6.2.1.2 An open polymer is viable, see Figure A3.

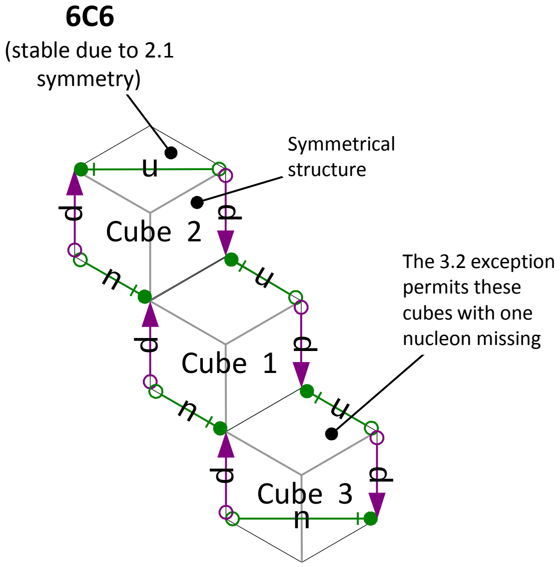


Open polymer
Protons are stable with
an externally open end
(but neutrons are not).
Applies to 2He1
(shown here) and 1H0.

Figure A3: Open polymer.

6.2.1.3 A limited number of opportunities exist for open polymer structures. Since they are open, they can omit one neutron from the chain. The open structures stop at two protons: adding a third closes the cube and therefore closes the nuclear polymer. Open polymers are therefore only available up to He.

6.2.2 Symmetrical structures are possible with simple series p#n (cis-phasic) polymer chains. These do not need to fill all the cubes, but they must be symmetrical. (The reason is tentatively that these unfilled cubes impose strain on the polymer, and the symmetry requirement ensures that the sum of the strain around the polymer will be zero). Stable Nuclides with p=n use the symmetrical layouts. See Figure A4.



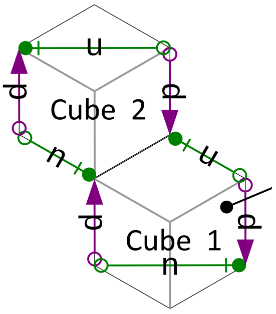
6C6
(stable due to 2.1
symmetry)

Symmetrical
structure

The 3.2 exception
permits these
cubes with one
nucleon missing

Figure A4: Symmetrical structure for 6C6 is stable. Note that the top and bottom neutrons are shown longer than the others, but this is simply for representative convenience: the actual shape is expected to be such that the strain is equally distributed throughout the polymer.

6.2.3 Symmetrical subassemblies require three or more cubes. Hence 6C6 (three cubes) is stable, but 4Be4 (two cubes) is not. The reasons are conjectured to be that the smaller structures have greater difficulty accommodating the strain. See Figure A5.



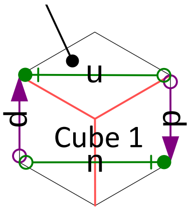
4Be4 (unstable)
This structure is
presumed not to be
viable.

Figure A5: Symmetrical structure for 4Be4 is unstable.

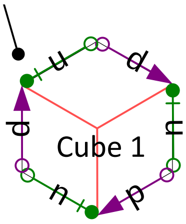
6.2.4 COMPLETE SUBASSEMBLIES are viable, but only certain filled shapes are complete. COMPLETE means that all expected edges must be occupied.

6.2.4.1 These are the LAMELLAR plate (4 nucleons), SINGLE CUBE (6 nucleons), 2-LINEAR CUBES, 3-CUBEs, 4-STAR and potentially others, see Figure A6.

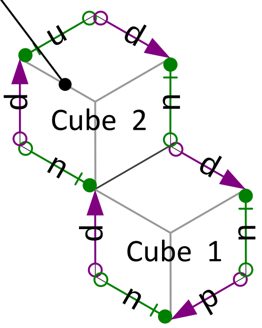
LAMELLAR plate structure.
Four nucleons in a square, for 2He2. This is the nominal representation: the actual shape expected to be equal strain on all members, i.e. the square is expected to be twisted.



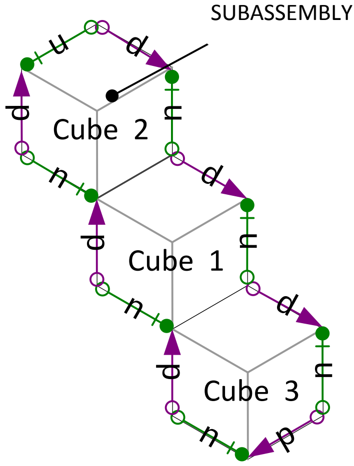
1-CUBE
The nuclear polymer fills one cube completely, for 3Li3.

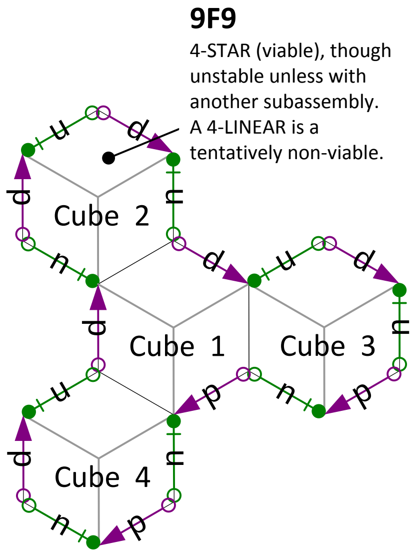


2-LINEAR
Here at 5B5 is the first occurrence of the 2-linear stable subassembly. This does not need a bridge neutron, because taken together both cubes are externally complete (whereas 4Be4 is not).



3-LINEAR
This is a complete SUBASSEMBLY.





9F9

4-STAR (viable), though unstable unless with another subassembly. A 4-LINEAR is a tentatively non-viable.

Figure A6: Acceptable forms of COMPLETE subassemblies.

6.2.4.2 We tentatively assume that the 4-CUBE LINEAR is unviable, and that the 4-STAR is viable (and merely unstable when on its own without another subassembly).

6.3.3 The requirements for a viable shape differentiate the stable and unstable nuclides from the non-viable ones. Stable nuclides have a viable shape AND an entirely p#n cis-phasic polymer, Unstable nuclides have a viable shape and may have some pxp or nxn trans-phasic elements to their polymer, and Non-viable nuclides (extremely short lives or non-existent) have difficulty finding a viable shape given the number of nucleons they need to accommodate.

NP.6.3 ASSEMBLIES OF DIFFERENT TYPES OF COMPLETE SUBASSEMBLIES ARE PERMITTED.

6.3.1 Such Assemblies must have COMPLETE subassemblies to be viable. (Open or incomplete layouts may not be mixed with complete subassemblies).

6.3.2 Viability permits only one of the same type of SUBASSEMBLY, except that two 1-CUBES joined at a BRIDGE are acceptable.

6.3.3 Assemblies require the inclusion of BRIDGE neutrons to create the partitions. See Figure A7.

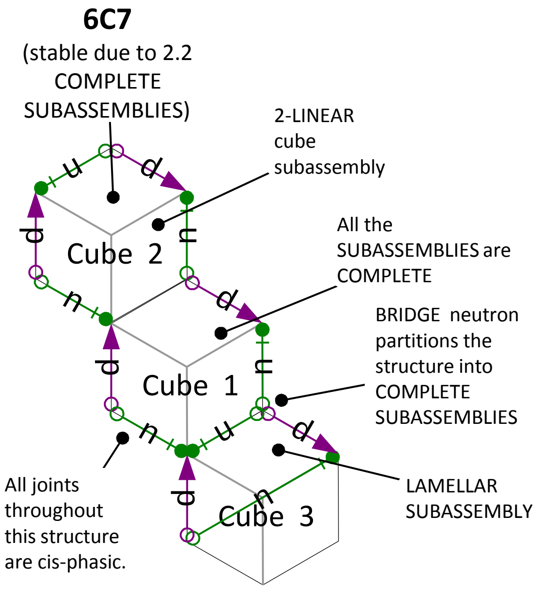


Figure A7: Complete subassemblies, as 6C7, are viable.

NP.6.4 A CUBE WITH ONE UNFILLED EDGE FILLED IS NON-VIABLE.

The reason is thought to be excessive strain in such structures.

6.4.1 A ring of five nucleons does not make a COMPLETE SUBASSEMBLY. (A COMPLETE cube may not have just a single nucleon missing). See Figure A8.

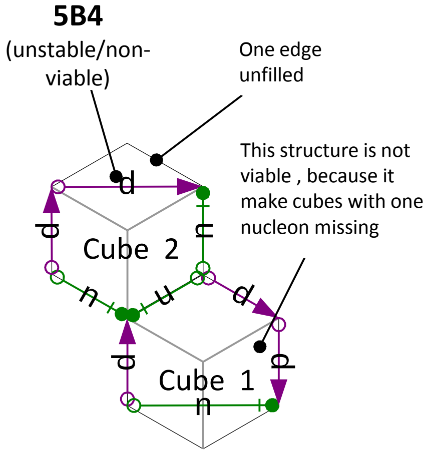


Figure A8: One unfilled edge in a cube is non-viable.

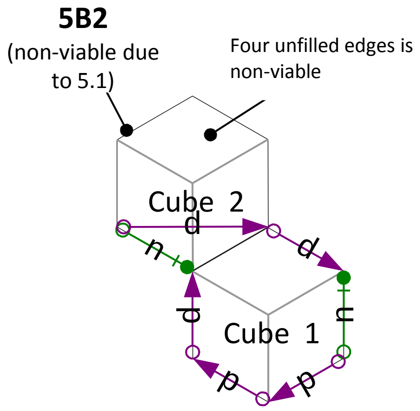
6.4.2 Exception: n=p polymers can have a single polymer missing from *each* of their end cubes (i.e. the symmetry requirement still applies).

NP.6.5 A CUBE WITH FOUR UNFILLED EDGES IS NON-VIABLE.

The reason is thought to be excessive strain in such structures.

6.5.1 A spike of two nucleons protruding into a cube (with or without a BRIDGE neutron) does not make a COMPLETE SUBASSEMBLY and is non-viable. See Figure A9.

6.5.2 The nuclear polymer may avoid this by not advancing into the affected cube, but rather placing the neutrons into BRIDGE positions elsewhere. This requires the existence of suitable such locations, which is not automatically always the case.

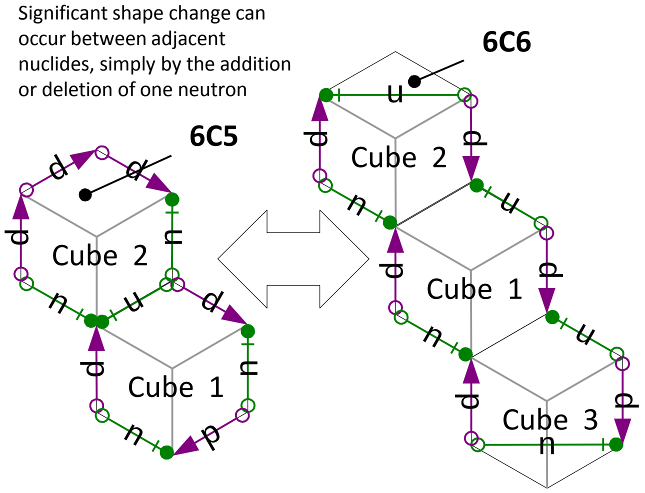

5B2
(non-viable due to 5.1)

Four unfilled edges is non-viable

Figure A9: Four unfilled edges in a cube is non-viable.

NP.6.6 SHAPE TRANSITION: THE NUCLEAR POLYMER IS ABLE TO QUICKLY REARRANGE ITS LAYOUT AS IT TRANSITIONS FROM ONE NUCLIDE TO ANOTHER.

6.6.1 Individual nucleons can be relocated to elsewhere in the polymer. Typical examples are the relocation of BRIDGE neutrons into a new CUBE. More substantial changes in shape are also possible, see Figure A10.


Significant shape change can occur between adjacent nuclides, simply by the addition or deletion of one neutron

6C5

6C6

Figure A10: The nuclear polymer is able to quickly rearrange its layout as it transitions from one nuclide to another.

6.6.2 The nuclear polymer is particularly vulnerable to external perturbation, hence disassembly and decay, at transition. (For example, see 5B4).

NP.6.7 OCCUPANCY: FOR VIABILITY EACH OCCUPIED CUBE MUST HAVE AT LEAST ONE NEUTRON AND ONE PROTON.

6.7.1 Applies to proton rich structures. It would seem to be a strong constraint in these cases: the principle cannot be violated, even fleetingly. See Figure A11.

6.7.2 Applies also to neutron rich structures.

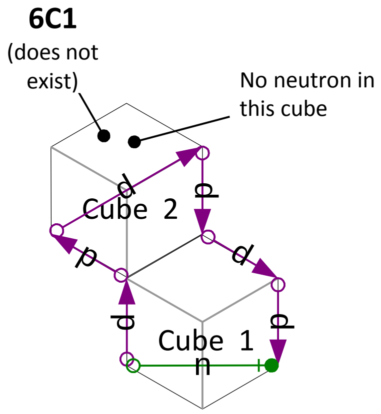


Figure A11: For viability each occupied cube must have at least one neutron and one proton.

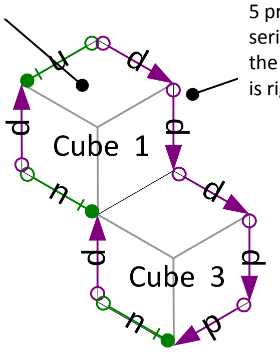
NP.6.8 TRANS-PHASIC CHAIN LIMITATION: TRANS-PHASIC CHAINS ARE NOT PERMITTED TO EXCEED A CERTAIN LENGTH OR DENSITY PER CUBE.

6.8.1 Trans-phasic Proton chains (pxp) are not permitted to exceed a certain length or density. That limit is currently believed to be about as many protons in series as there are cubes in the polymer. This applies to proton rich structures. Thus a plain chain of protons cannot be achieved. This is believed to be a strong constraint. The reason is presumably because the strong handedness constraints of the protons cannot be accommodated. See Figure A12.

6.8.2 Trans-phasic neutron chains (nxn) are not permitted to exceed a certain length. That limit is currently believed to be about as many unfixed neutrons in series as there are cubes in the polymer. The reason is presumably because the neutrons are too accommodating, and therefore the structure lacks stiffness or becomes indeterminate at the re-energisation cycles. Interspersing protons limits the chain length, but proton continuity needs to be maintained.

6.8.3 The above limits are dependent on the shape (symmetrical polymers are less tolerant than complete subassemblies), and the number of cubes, and are tentative.

7N3
(unstable, to
the point of
doubtful
viability)



5 protons in
series is pushing
the limits, and 6
is right out

Figure A12: Trans-phasic Proton chains (pxp) are not permitted to exceed a certain length or density.

NP.6.9 PROTON CONTINUITY

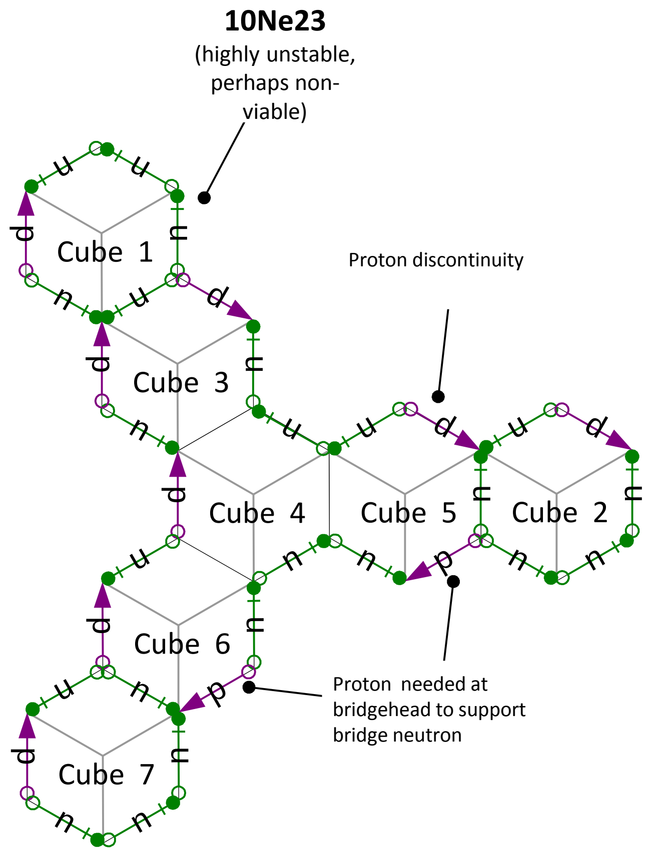
6.9.1 For viability of neutron rich structures, the protons must all be connected via single neutrons, i.e. isolated protons are disfavoured. There needs to be a continuous chain of cis-phasic proton-to-neutron units

6.9.2 While the polymer as a whole must be closed, the proton-neutron chain component does not need to be: the protons need only be connected at one end, and neutrons may close the rest of the loop.

6.9.3 The proton-neutron chain may be branched.

6.9.4 Isolated neutrons -separated by two or more neutrons- or isolated proton-neutron chains, have poor viability. See Figure A13.

6.9.5 This requirement causes viability crises in some of the neutron rich nuclides, but is not the reason for the termination of the series (for that see the Occupancy requirement).



10Ne23
(highly unstable, perhaps non-viable)

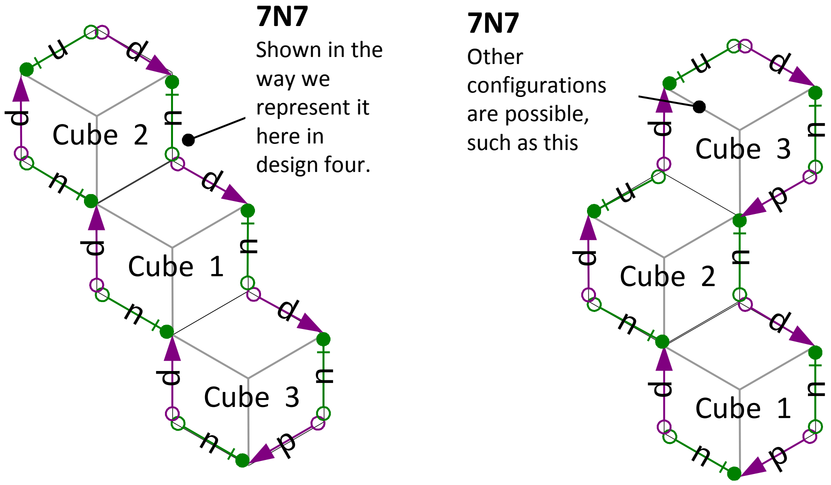
Proton discontinuity

Proton needed at bridgehead to support bridge neutron

Figure A13: Nuclei with isolated proton-neutron chains have poor viability.

NP.6.10 SHAPE IS UNCERTAIN

The arrangement of the cubes depends on the details of the HED mechanics, which are incompletely understood. Consequently we can at this time only predict the general cube configuration - usually there are several sub-variants and we cannot yet select between them, see Figure A14 for some 7N7 shapes. Consequently the structures proposed are merely representative of how the nuclear polymer occupies the cubes.



7N7
Shown in the way we represent it here in design four.

7N7
Other configurations are possible, such as this

Figure A14: The arrangement of the cubes is not fully known. Two options are shown here.

B APPENDIX: NUCLIDES FROM HYDROGEN TO NEON

[Online attachment only]

The attached chart details the predicted Cordus structure of each nuclide. Raw data for lifetimes are courtesy IAEA (http://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html).

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[i] *Inner and outer structure of the Cordus particule:* The basic idea is that every particle has two reactive ends, which are a small finite distance apart (span), and each behave like a particle in their interaction with the external environment. A fibril joins the reactive ends and is a persistent and dynamic structure but does not interact with matter. It provides instantaneous connectivity and synchronicity between the two reactive ends. Hence it is a non-local solution: the particule is affected by more than the fields at its nominal centre point, and a principle of *Wider Locality* applies. Each reactive end of the particule is energised in turn at the frequency of that particule (which is dependent on its energy). The reactive ends are energised together for the photon, and in turn for matter particules. The frequency corresponds to the de Broglie frequency. The span of the particule shortens as the frequency increases, i.e. greater internal energy is associated with faster re-energisation sequence (hence also faster emission of discrete force and thus greater mass). When the reactive end is energised it emits discrete forces in up to three orthogonal directions. The quantity and direction of these are characteristic of the type of particule (photon, electron, proton, etc.), and the

differences in these signatures is what differentiates the particules from each other. Although for convenience we use the term discrete *force* for these pulses, the Cordus theory requires them to have specific attributes that are better described as *latent discrete prescribed displacements*. This is because a second particule that subsequently receives one is prescribed to energise its reactive end in a location that is slightly displaced from where it would otherwise position itself. Thus in the Cordus theory, that which we perceive as force is fundamentally the effect of many discrete prescribed displacements acting on the particules, a kind of coercive displacement. These discrete forces are connected in a flux line that is emitted into the external environment. (In the Cordus theory this is called a hyperfine-fibril, or hyff). Each reactive end of the particule emits three such orthogonal hyff, at least in the near-field. The exception is the photon, which only emits radially. These directions are relative to the orientation of the span, and the velocity of the particule, and termed hyperfine-fibril emission directions (HEDs). The axes are named [r] radial outwards co-linear with the span, [a] and [t] perpendicular to the span and to each other. These are so-named for consistency with our previous nomenclature for the photon, but when applied to massy particules do not necessarily imply motion. It is proposed that the quarks and other leptons follow the same pattern, though in the case of the quarks not all the hyff emission directions [r,a,t] are filled (hence their fractional charge). In this theory electric charge is carried at 1⁄3 charge per discrete force, with the sign of the charge being determined by the direction of the discrete force element. So the number and nature of energised HEDs determines the overall electric charge of the particule. The aggregation of discrete forces from multiple particules creates the EMG fields, which are thus discrete. The combined emission discrete forces makes up a 3-D composite structure. The direct lineal effect of the discrete force provides the electrostatic interaction, the bending of the hyff flux line provides magnetism, the torsion provides gravitation interaction, and the synchronicity between discrete force elements of neighbouring particules provides the strong force. These are all carried simultaneously by the composite discrete force element as it propagates outwards on the hyff flux. Assembled massy particules compete spatially for emission directions, and may synchronise their emissions to access those spaces. Thus there is mutual negotiation in the near-field between interacting particules, based on shared geometric timing constraints. These particules interact by negotiating complementary HEDs and synchronising the emission frequencies of their discrete force elements. This synchronicity is proposed as the mechanism for the strong force and for coherent assemblies. The same mechanism, acting through coherent assemblies of electrons, explains molecular bonding. Thus the Cordus theory provides force unification by providing a model for electro-magneto-gravitational-synchronous (EMGS) interactions as consequences of lineal, bending, torsion, and synchronicity effects respectively. The discrete force element is a 3-D composite structure, with a hand defined by the energisation sequence between the axes. This

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hand provides the matter/anti-matter species differentiation, which are denotes dexter and sinister respectively. We acknowledge that we have not described *what* these discrete forces and flux tubes comprise. Instead, the design method used to develop the Cordus theory simply shows that having such elements is a logical necessity for this solution.

[ii] Cis-phasic joints are where the reactive ends, one from each of two particules, are co-located, have the same frequency and are in-phase. The trans-phasic joint also involves co-location of the reactive ends, synchronous frequency, and the strong force, but the difference is that the particules are at opposite phases in their energisation sequences.