CAUSALITY, 4-GEONS AND DARK ENERGY: A RADICAL VIEW OF SPACE-TIME

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Abstract

A discussion of space-time and causality is presented within a relativistic framework but with a consideration of quantum physics, from both a philosophical and physical perspective, in response to "On the Feasibility of Time Travel and Its Implications" by Amaral. This discussion leads to an argument in favour of 4-geons as introduced by Hadley; hypothesised particle-like structures in space-time with closed time-like curves that generate aspects of quantum physics from within general relativity. 4-geons are then used to propose a novel and testable model for 'dark energy' in terms of negative mass singularities along with a heuristic explanation for large-scale causality that includes the arrow of time. The argument assumes the 'open-endedness conjecture' introduced by the current author in "An Example 4-Geon." The end result is a model that manifests small-scale acausality and large-scale causality, compatible with both quantum and relativistic physics. This shows Einstein's field equations need no cosmological constant or alteration in order to be consistent with cosmological observation. Further, mass and charge become properties of the topology of space-time and the classical limit reduces to the electro-vacuum solutions, showing that there are more approaches to unification than are generally considered. The paper closes with a discussion of 'free will' noting that under the open-endedness conjecture 'free will' would be indistinguishable from a measurement.

Causalité, 4-Géons et l'Énergie du Vide: Une Vision Radicale de l'Espace-Temps

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Résumé

Une discussion de l'espace-temps et de la causalité est présentée à l'intérieur d'un cadre relativiste mais en considérant la physique quantique, d'une perspective à la fois philosophique et physique, en réponse à « La Faisabilité du Voyage dans le Temps et ses Implications » par Amaral. La discussion mène à un argument en faveur du 4-géons tel qu'introduit par Hadley; des structures hypothétiques de type particule dans l'espace-temps avec des courbes fermées de type temps qui génèrent des aspects de la physique quantique à l'intérieur de la relativité générale. Les 4-géons sont donc utilisés pour proposer un nouveau modèle testable pour 'l'énergie du vide' en termes de singularités de masse négative ainsi qu'une explication heuristique de la causalité à grande échelle qui inclut la flèche temps. L'argument suppose la 'conjecture d'ouverture' introduit par l'auteur actuel dans « Un Exemple de 4-Géon. » Le résultat final est un modèle qui manifeste l'acausalité à petite échelle et la causalité à grande échelle, compatibles avec les modèles de physique quantique et relativiste. Cela démontre que l'équation de champs d'Einstein ne nécessite pas de constante cosmologique ou d'altération pour être en accord avec l'observation cosmologique. De plus, la masse et la charge deviennent des propriétés de la topologie de l'espace-temps et la limite classique se réduit aux solutions électro-vides, démontrant qu'il y a plus d'approches à l'unification que ce qui est généralement considéré. L'article conclu avec une discussion sur le 'libre arbitre' notant que sous la conjecture ouverte, le 'libre arbitre' ne serait pas distinguable d'une mesure.

Causalidad, 4-Geons y Energía Obscura: Un Punto De Vista Radical del Espacio-Tiempo

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Extracto

Se presenta una discusión del espacio-tiempo y la causalidad dentro de un marco relativístico pero con una consideración de física quantum, ambos desde una perspectiva filosófica y física, en respuesta a “Sobre La Posibilidad De Viajar En El Tiempo Y Sus Implicaciones” por Amaral. Esta discusión lleva hacia un argumento en favor de 4-geons según introducido por Hadley, presentando la hipótesis de estructuras como partículas en el espacio-tiempo con curvas como-tiempo cerradas que generan aspectos de física quantum desde dentro de una relatividad gen eral. Entonces se usan 4-geons para proponer un modelo nuevo y comprobable de “energía oscura” en términos de singularidades de masa negativa junto con una explicación heurística para la causalidad en gran escala que incluye la flecha del tiempo. El argumento asume la “conjetura de un final abierto”, introducida por el presente autor en “Un Ejemplo 4-Geon.” El resultado final es un modelo que manifiesta una causalidad en pequeña escala y una en gran escala, compatibles ambas con la física quantum y la relativística. Esto muestra que las ecuaciones del espacio de Einstein no necesitan un constante cosmológico o una alteración para ser consistentes con la observación cosmológica. Además, la masa y la carga se convierten en propiedades de la topología del espacio-tiempo y el límite clásico se reduce a las soluciones del electro-vacío, demostrando que hay más maneras de encararse a la unificación que las generalmente consideradas. El artículo termina con una discusión del “libre albedrío” denotando que bajo la conjetura de un final-abierto, el “libre albedrío” sería indistinguible del de una medida.

Causalidade, 4-Geons e Energia Escura: Uma Visão Radical Do Tempo- Espaço

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Sumário

Uma discussão sobre tempo-espaço e causalidade é apresentada dentro de uma estrutura relativa, mas com uma consideração da física de quantum, de uma perspectiva filosófica e física, em resposta a "na Possibilidade de Viagem ao Tempo e suas Implicações" por Amaral. Esta discussão leva a um argumento em favor de 4-geons como introduzido por Hadley; estruturas hipotetizadas, como partículas, no tempo-espaço com curvas fechadas, como tempo, que geram aspectos da física de quantum dentro da relatividade geral. 4-geons são então usados para propôr um modelo novo e que pode ser testado para a ‘energia escura’ em termos de singularidades de massa negativa, junto com uma explicação heurística para a causalidade em grande escala que inclui a seta do tempo. O argumento assume a conjetura introduzida pelo autor atual em “Um Exemplo de 4-Geon." O resultado final é um modelo que manifesta a causalidade em pequena escala e em grande escala, compatíveis com a física de quantum e também relativista. Isto mostra que as equações de Einstein não precisam de alguma constante ou alteração cosmológica a fim de ser consistente com a observação cosmológica. Além disso, a massa e a carga tornam-se propriedades da topologia do tempo-espaço, e o limite clássico se reduz às soluções do eletro-vácuo, mostrando que há outras maneiras para unificação do que o que é considerado normalmente. O artigo conclui com uma discussão sobre o livre arbítrio, observando que sob a conjetura mencionada, o 'livre arbítrio' não se distingue de uma forma de 'medida'.

Kausalitaet, 4-Geons und dunkle Energy: Ein radikaler Blick auf Raum-Zeit

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Zusammenfassung

Im Ramen der Relativitaet wird eine Diskussion der Raum-Zeit dargeboten, jedoch mit Ruecksicht auf Quantumphysik und aus philosophischer, sowie physikalischer Perspektive. Auch ist es eine Reaktion auf die Schrift "On the Feasibility and of Time Travel and its Implications" von Amaral. Die Dikusssion fuehrt zu einem, von Hadley bekannt gemachten, Argument fuer 4-Geone; hypothesierte Teilchen-gleiche Strukturen in der Raum-Zeit mit geschlossenen Zeit-gleichen Kurven die, innerhalb der Generellen Relativitaet, Aspekte der Quantum Physik entwickeln. 4-Geone werden dann angewandt ein testbares Model fuer "dunkle Energie" aufzubauen, und zwar mit Bezug auf Singularitaeten negativer Masse zusammen mit einer heuristischen Erklaerung fuer eine0 grossangelegte Kausalitaet die den "Pfeil der Zeit einbetreffen". Das Argument setzt die "open-endedness conjecture" voraus, die vom gegenwaertigen Verfasser in "An Example 4-Geon" vorgestellt wurde. Das Endresultat ist ein Model, dass Kausalitaet auf grosser wie auf kleiner Ebene manifestiert und mit Quantum- sowie mit Relativistischer Physik vereinbar ist. Es zeigt, dass Einsteins Feldgleichungen weder kosmologische Konstanten noch Aenderungen benoetigen, um mit kosmologischen Beobachtungen vereinbar zu sein. Weiterhin werden Masse und Ladung zum Bestandteil der Topologie der Raum-Zeit und die herkoemmliche Begrenzung wird zur Elektro-Vacuumloesung reduziert. Dies zeigt, dass es mehr Wege zur Vereinigung gibt als allgemein angenommen wird. Die Schrift schliesst mit einer Diskussion des freien Willens und notiert, dass es unter der "open-endedness conjecture" keinen Unterschied zwischen freiem Willen und Messung geben wuerde.

INTRODUCTION

As is well-known there are two main physical theories, or groups of theories, which describe the laws of physics as they are currently understood, (i) the theory of general relativity, the large-scale theory of space and time [60][38][26][55][16][62], the theory primarily used by cosmologists and originally formulated by Einstein, and (ii) the small-scale theory used to study the nature of atoms and particles, that of quantum mechanics [5][41]. That the two seem mathematically inconsistent, that a new theory is needed to unify and encompass them, is known as the problem of unification. All attempts at unification, including the contemporary string theory, remain incomplete and unproven.

It is therefore, pragmatically, primarily general relativity and quantum mechanics that should guide us in any assessment as to what 'space' and 'time' actually might be, they are as it were, the collective summary of our *physical experience*. For an alternative view see [61]. For philosophers the problem also includes our *psychological experience* [42], even spiritual experience. 'Causality' and related concepts such as 'the arrow of time' have a prominent role in both science and philosophy [37][56][6][54][1][2][67][25][59][42][30], though its nature in general relativity is different from that in quantum mechanics, and different again from that which we are likely to be familiar with in our psychological experience. For information on the physics of the 'arrow of time' see [40][21][22][19]. There is a plethora of ways to define different types of causality mathematically on hypothetical space-times [28], yet 'causality' is also a subjective experience rather than a mathematical definition, at least in its initial conception. It is bound up with a subjective sense of time and 'the arrow of time.'

One of the primary approaches to unification is called quantum gravity; the approach is to look at what the universe is made of, brick by brick, atom by atom as it were, and build it up from there, hopefully reaching an approximation to general relativity when all relevant processes have been taken into account: a quantum theory of gravity. If you want to understand how a machine works, look at the parts, that is the philosophy. Here the complementary approach is explored: starting from general relativity, from our broadest conceptions of space and time, why not look to see in what ways the basic ideas can be altered or extended to embrace as many facets of quantum mechanics as possible? Looking at the big picture first, that is the approach taken here.

So, what about our psychological experience? Can we apply our subjective observations [63] of causality and time (or 'acausality' [42] as the case may be according to Jung) in any way to our understanding of the physical world? The tentative answer given here is 'yes', but this will be done only with care, and minimally. For example, the time-travel problem or 'grandfather paradox' [1]: whether the Universe can or cannot allow us to time-travel so that we could prevent our own birth by killing one of our grandfathers. This leads to logical absurdities.

An important question to consider is what scientific status such philosophical arguments should receive. Einstein's famous statement about causality: "God does not play dice" (in objection to quantum mechanics) warns us that philosophy can lead the theorist away from useful empirical models. Yet, on the other hand, both Newton's and Einstein's deterministically inclined views undoubtedly contributed to their discoveries.

This paper assumes a basic understanding of the curved space-time of general relativity (a quick and easy layperson's introduction can be found in [47]), a conceptual familiarity with quantum mechanics and also entropy, plus a familiarity with special relativity, from which general relativity is extrapolated [26]; there is therefore, as with Newton's laws, no escape from the use of mathematics and mathematical concepts in their description. At no time, however, is it to be forgotten that the basis of modern science is experiment, or at least observation, and mathematics is but a best-fit description of this knowledge. What is also of interest methodologically, however, are the 'edges'; where the concepts of what constitutes an experiment, or what is definable mathematically are pushed to their limits, and when the 'objective' necessarily encounters such difficulties as the 'subjective,' as it must when science investigates 'causality.' A new approach to a general philosophical foundation to such issues is presented by the current author in [63].

This paper starts with a combined philosophical and empirical discussion on causality in the section "A Philosophical Discussion About Causality," particularly with respect to general relativity, in response to a previous paper in this journal "On the Feasibility of Time Travel and Its Implications" by Amaral [1]. The discussion acts as a prelude to the introduction of the concept of the 'geon' [24][56][45][65][66][44][49][27] and '4-geon' [31][32][23][33][34] and the possible application of these to physics in the sections "Geons and Spacetime" and "4-Geons and Spacetime" respectively. Geons have a chequered history from the origination of the idea with Einstein [24][56], their development by Wheeler [65][66], its subsequent dismissal by mainstream science, and the recent extension of the idea to '4-geons' introduced by Hadley [31][32]. A new and testable hypothesis is presented—an outline explanation for so-called 'dark energy' in"4-Geons and Dark Energy." A recent paper by the current author [64] "An Example 4-Geon" gives an example '4-geon,' along with certain machinery that is needed to interpret 'measurement' called the 'open-endedness conjecture,' this conjecture is then used as the basis for a heuristic explanation for the large-scale appearance of causality out of a small-scale space-time without causality in the section "A Heuristic Explanation for Time." The argument appears powerful in its explanatory power and includes an explanation for the asymmetry known as the 'arrow of time' [40][21][22][19][30]. "A Summary Including The Connection Between 4-Geons and Causality" is then included for clarity. Some philosophical consequences are investigated in "The Open-Endedness Conjecture and Free Will" leading to the "Conclusion."

Under the model developed in this paper a view of mass and charge as properties of the topology of space-time is formed in the spirit of [27] and [17] with the classical limit reduced to a subset of general relativity called the electro-vacuum solutions. This reduction of the classical limit could be a step towards unification.

A PHILOSOPHICAL DISCUSSION ABOUT CAUSALITY

In a previous paper in this journal "On the Feasibility of Time Travel and Its Implications," Amaral discusses solutions to general relativity that allow 'time travel.' This section expands upon the issues raised by Amaral.

Often theoretical physicists assume a definition of causality such that the grandfather experiment cannot be performed; the standard definition of space-time as used in cosmology [38] assumes a causal structure known as time-orientability [28]. Other common ways to theoretically impose causality include the cosmic censorship hypothesis [52] but there are many others [28]. Theorists on occasion drop causality constraints, so time-travel issues as raised by Amaral necessarily result. This leads to the 'grandfather paradox.' This is interesting because the resolution to this and similar issues may involve, in addition to objective observation, a psychological or 'subjective' [63] input to science. 'Causality' directly relates to our psychological experience and practical concepts of time via the logical problem of performing the grandfather paradox as an actual, or thought, experiment. This is both a subjective issue of causality, "do we have the free will to perform such an experiment?" and an experimental one; more prosaically, but really equivalently, "can the experiment be done?". In the case that the experiment can be done, the end result is a logical paradox, not least of all because we have other subjective notions such as a sense of choice, and the more weighted phrase 'free will,' that are bound up with 'time' and 'causality': and that for an experiment to be repeatable and meaningful we must have some sort of 'free will' or choice in the first place!

Relaxing constraints of causality leads to many 'solutions' in general relativity that imply time-travel to be consistent with theory, and perhaps even experimentally performable [39]. In a previous paper in this journal Amaral [1] describes some of the more important examples.

Amaral suggests a solution to the time-travel paradox with the idea of a past that can vary as freely as the future. In so doing, however, he undermines the mathematical basis of general relativity, in that it can no longer be based on the usual mathematical definition of a space-time as a 4- dimensional Lorentz manifold [38] without significant adaption, and therefore, to a certain extent, the logical flow of his argument is impeded. In modern cosmology, and within general relativity, space-time is generally defined [38] to be a 4dimensional, time-orientable Lorentz manifold with signature (3,1). The causal element of this is time-orientability. The 3 dimensions of space and 1 of time that are locally those of special relativity are referenced in the mathematical structure of the (3,1) signature. The signature is defined in terms of properties of a 4x4 matrix called the metric tensor and this underpins the definition of the curvature of space-time. Without this mathematical basis, such important features as the compatibility condition [60] fail. Failure of the compatibility condition means that the assumptions of general relativity no longer imply that space-time appears locally Minkowskian as is needed for compatibility with special relativity, and therefore the derivation of Newtonian gravity as a limit, the very point of general relativity, would cease to be mathematically valid. Amaral overlooks the perspective that in the most common formulation of general relativity the future is not free but is entirely determined by the past, or a sort of 'present,' via what are called 'Cauchy hyper-surfaces.'

Amaral proceeds, however, in a follow-up paper [2] to put his ideas firmly in the quantum gravity category and thus side-steps this definitional problem; his conclusion is that a network of entanglements could form the underlying structure, and he may well be right; however, to that extent his arguments lose their basis in general relativity, and therefore their immediate relevance here. The concept of 4-geons presented in this paper is mathematically rooted in general relativity, whilst also sharing commonality with Amaral's 'entanglements.'

So, taking the space-time route consistent with the stated approach, do we disallow all causality violating space-times? Or do we allow all causality violating space-times in our definition of space-time? Or something else altogether?

There is little experimental evidence at the large-scale for the existence of non-causal structures, that is, for the relaxation of the time-orientability condition and the existence of what are called closed time-like curves [25][59][29]. But there are theoretically possible experiments; however, experimental testing at the large-scale to determine what is and what is not the case is often prohibitive. The construction of a Tipler cylinder, for example, it has been suggested, could be done in principle by fusing neutron stars together [1][50] and thus creating closed time-like curves.

Amaral [1] does however reference observational evidence for time-loops, the equivalent of a galactic-scale Young's slit experiment that occurs in astronomy, with the following conclusion:

"…the only answer is that something travelled back in time along the light beam telling the light particles to behave differently."

Whilst this may not be the only explanation, it is clear from his argument that time-orientability is in doubt or even invalidated. But if time-orientability does not apply, it does *not* follow that no causality constraint of any sort exists on large-scale space-time; on the contrary, by far the largest part of our large-scale observations remain causal, as do the largest part of our subjective experiences.

At the human scale the time-travel of a person would necessarily not comply with a normal psychological waking state, the paradox of time-travel remains under normal circumstances, and in the general case, a logical contradiction without altering the basis of space-time greatly. This is because it leaves open the possibility of the following logical paradox: a normal waking state of existence which exists and doesn't exist at the same time, as the grandfather paradox makes clear. A premise behind this paradox is a subtle version of free will: that we can perform experiments freely and repeatably. We cannot take away this premise without detailed rethinking of the logic of empirical science or alternatively without putting a causality constraint on space-time. Yet this premise is essentially a *subjective observation* of the normal human waking state, of ourselves and our 'free will' in performing experiments;, the paradox does not occur for electrons and atoms and such like. Therefore, strangely, 'objective' science assumes a 'subjective' observation as a premise, and this leads afresh to a discussion of 18th century philosophical debates such as Bishop Berkeley's subjective empiricism [9], where empiricism is considered meaningful only to the extent that it relates to subjective experience. For most practical purposes this view can be misleading and confusing, but in this context, that is, since the causality of Newtonian physics has been replaced by the complications of modern physics, it regains practical merit.

But what is more, there *is* an example of a state that explicitly exists and doesn't exist at the same time in science, and indeed where the same issues of contradiction appear. However, not this time in cosmology, but instead in quantum mechanics. The famous thought experiment of Schrödinger's cat illustrates well the quantum mechanical principles of superposition and the apparent paradox that goes with it [54]. Under the rules of quantum mechanics, the cat is in a superposition of 'dead' and 'alive.' As with the grandfather paradox, this appears paradoxical on subjective grounds, since the cat could equally be exchanged by our own normal waking state!

The conclusion then, on empirical grounds rather than deductive logic, is that at the large-scale there is generally some sort of causality constraint on space-time, but that it is generally scale dependent, and is somehow relaxed, weaker, or less frequent, at smaller scales. And further, that it may actually lead to some of the differences between quantum and gravitational physics that appear to be related to this issue. If there is a place for the mind of a cat, a physicist, or a hapless volunteer in all of this, it would be no surprise to find them somewhere between the two scales, in such a place that the grandfather paradox would not really be achievable (with all generality) and where the Schrödinger's cat paradox would not be as stark as its quantum mechanical formulation suggests.

Two conclusions can be proposed:

Remark 1: That in all probability there is a large-scale constraint on causality, but that this may be weaker than, or different from, the time-orientability of space-time usually assumed.

Remark 2: There is little reason to impose causality constraints on space-time at the small-scale. This may account for some of the differences between large-scale physics and quantum physics.

N.B. It should be noted that quantum mechanics is not defined on a space-time fully compatible with general relativity, but that some variants, i.e. relativistic quantum mechanics, use the flat Minkowski space-time of special relativity. 'Remark 2' must therefore be interpreted with this proviso in mind.

As stated, these tentative conclusions can be argued on empirical grounds, including a subjective input from subjective experiences of how we perceive time, that is, a form of subjective empiricism. The danger, as with any empiricism, is to take the extrapolated conclusions from observation as absolute truth, a common source of errors imposed on science by deductive reasoning, i.e., a failure to recognise the limits of the scale and scope of our observations—whether objective or subjective.

The above two remarks will be used in an argument shortly that provides testable physical predictions, thus taking the causality bull by the two horns, as it were, of philosophy and experiment.

Other arguments in favour of a space-time without the usual construct of time are presented by Barbour in [6].

A Fun Observation

In a paper by Stephen Hawking [36] it was shown that closed time-like curves lead to a breakdown of quantum coherence. Arguments presented by Roger Penrose [54][53] suggest that quantum coherence may be essential to the operation of the brain, and therefore the human mind.

We may therefore guess that time-travel could have deleterious effects on the functioning of any would be time-traveller!

An Anthropic Note

It is interesting to note the similarity between using (i) the subjective observation of causality as a physical argument and (ii) anthropic arguments generally [7][63]. That is, it is essentially an anthropic argument to state that the Universe must be such as to allow our perception of causality to exist. Further, some anthropic arguments, such as the strong anthropic principle [7], can be reinterpreted as a form of subjective empiricism.

Further Thoughts

For some, further thoughts on the connections between science and philosophy, from such scientists as Einstein, Heisenberg, De Broglie, Pauli, and Planck see *Quantum Questions* edited by Wilber [67]. Schrödinger's *What is Life?* and *Mind and Matter* are also interesting [57]. Roger Penrose's *The Emperor's New Mind* [54] and *Shadows of The Mind* [53] , Barrow and Tipler's *Cosmological Anthropic Principle* [7] and Wheeler's *Geons, Black Holes, and Quantum Foam: A Life in Physics* [65] also expose the philosophical thoughts of prominent physicists. From another sort of empiricist, Carl Jung, for his thoughts (subjective empirical observations and conclusions) on causality, see *Synchronicity* [42]. For information and discussion on the physics of the 'arrow of time,' see [4][40][21][22][19][30].

GEONS AND SPACE-TIME

"Qu'est ce que l'atome?" – [46]

In a previous edition of this journal, Myara [46] enquires into the nature of the atom, and discusses other concepts such as energy and gravitation, presenting some historical and philosophical perspectives on these ideas. The concept of 'geon'[65][66], as will be described, is able to unify all these concepts: matter, energy, and gravitation into a single mathematical structure: space-time itself.

The geometry of General Relativity is based on the concept of a manifold, an abstract extension of the idea of a curved surface, or more particularly a Lorentz manifold of signature (3,1), usually with the constraint that the manifold is time-orientable [38]. Einstein's field equations determine how mass, energy and momentum affect the curvature of space-time via a 'stress-energy' tensor and then this curvature determines the motion of the matter along certain lines of least resistance called geodesics, thus explaining gravity. As is well-known, these equations lead to 'black holes' which are mathematical holes in the geometry of space-time. These holes and related structures are often called 'singularities.' Some of these singularities can be 'fixed' by joining a bridge from one hole to another, producing the familiar science fiction wormhole, though in the simplest cases there is doubt as to the stability of these structures [39]. The mathematical subject that deals with this kind of deformation (i.e. holes and bridges) on manifolds is called topology and adds properties to space-time that can no longer be encompassed only by the curvature of geometry. We now have geometry and topology.

One of the possibilities with wormholes is that if one mouth of the wormhole is placed significantly back in time with respect to, or otherwise sufficiently far from, the other, then you get closed time-like curves, that is, time-loops – or simply the possibility of time travel. This contradicts the usual assumption of time-orientability that, under the hypothesis, has to be discarded; it is no longer clear which direction is 'past' and which is 'future.' In this way topology directly relates to causality in a space-time model of the Universe.

The source of mass in general relativity is a perennial problem, since general relativity is valid at the large-scale; yet mass sources, generally particles, are modelled accurately only at the small scale, and in quantum mechanics also have wave-particle duality and quantum behaviour, complicating models further. So-called matter models must be added by hand in order to make general relativity run smoothly [24][65][60][38]. These matter models must be consistent with various parameters and are not trivially constructed. The content of the matter models, however, is generally nothing other than localized constraints on space-time curvature imposed by a 'stress-energy' tensor [60][38], i.e., they consist of nothing more than geometry. This leads to the idea that matter could be nothing other than geometrical curvature. The same argument can be applied analogously to energy and momentum; in special relativity momentum and energy form a single quantity, or 4-vector, called momenergy, and energy is identified with mass in the special relativity formula $E = mc^2$ or $E = \gamma mc^2$ [60]. Energy also has a related role to matter in the definition of the stress-energy tensor [60].

Einstein first suggested [31][32][24][45][65] the neat solution to the problem of matter using this idea: that particles could be purely geometrical or topological structures in space-time. Topology imposes mathematical constraints on geometry and vice versa. Such topologically imposed geometry can then be identified with the mass of the hypothesised particle, and with appropriate definitions satisfy all the requirements of a matter model without any additional assumptions. The construction of other particle-like solutions out of space-time without topological deformations has also been attempted [65][66][44][45]. These two types of hypothetical particle-like solutions are known as 'topological geons' and 'geons' respectively. By these definitions black holes become a type of geon. The similarity between the electron and a type of charged spinning black hole (or singularity) called the Kerr-Newman solutions is evidenced in the literature [17] and related discussions in [65][66][31][32][27][23][17][8][33][3][34]. In this light, research on multiple black hole solutions to general relativity is particularly interesting [11][13].

Considering multiple black hole solutions, when no electromagnetic field is required, it is clear that matter models could be constructed purely with the masses of singularities. These solutions would be 'source free' because they require no mass that is not explicitly a result of the gravitational effects of singularities or gravitational waves. Wheeler refers to this idea in the context of non-topological geons as "mass without mass" [65], in some cases using additional electromagnetic fields. The result is, excluding electromagnetic fields, a simplification of Einstein's field equations to the 'source free' field equations [60], which amounts to nothing other than the simple constraint that the space-time manifold be 'Ricci flat.' The mathematical payoff for this simplification in the field equations is paid for at the price of topological complexity. While topological complexity makes life difficult for the mathematician, it actually simplifies the assumptions, since the restrictive assumption of topological simplicity has been removed!

Similarly, wormhole-type geons could also be given electromagnetic charges without actually requiring a charge source (Wheeler's "charge without charge" [66][31][32][23][33][34][3][17][27] first envisaged by Herman Weyl in the 1920s [65]). One mouth having field lines emanating from it as if it were a positive charge, and those same field lines passing through the wormhole to the other mouth, so that it would then appear to have an equal negative charge on the other side. If this were done for all charged particles, and including the mass simplification mentioned above, Einstein's field equations would simplify to what are called the electro-vacuum solutions [60] by definition. We can make a further restriction to the non-null case on account of the fact that the so-called null solutions are relatively idealized and unrealistic. Conservation of energy, the stress-energy tensor, the compatibility condition and therefore all of Newton's laws and special relativity, the Lorentz force law, mass, charge and the nature of momentum/energy would all be expressed at the classical limit by these relatively simple equations – one equation, the first below, defining space-time curvature and the other, the second below, being simply the source free Maxwell's equations of electromagnetism, presented here for completeness:

$$G^{ab} = 2\left(F^{a}{}_{j}F^{jb} - \frac{1}{4}g^{ab}F^{mn}F_{mn}\right)$$

$$F_{ab;c} + F_{bc;a} + F_{ca;b} = 0 \quad \text{and} \quad F^{jb}{}_{;j} = 0$$

The Lorentz force law, for example, follows from these equations (except in a few exceptional cases) as demonstrated on page 472 and 473 of [60] where the equations appear in a slightly different form but describe the same solutions.

Remark 3: Topological geons and the argument provided above could therefore simplify the classical limit of physics to the (non-null) source free electro-vacuum solutions.

N.B. The non-null electro-vacuum solutions can be summarized in a few algebraic and differential axioms based purely on geometry called the Rainich conditions. The Rainich conditions and the arguments above correspond to the 'already unified theory' (of gravity and electromagnetism) of Rainich, Misner and Wheeler [65].

Despite the upsides, the stability issues associated with simple wormholes [39] and geons generally [49] has dampened enthusiasm in mainstream research for geons [65][66], and many theorists doubt that stable geon solutions of this nature are possible. In addition, the issue of dark energy and the acceleration of cosmic expansion [48][14] has made it possible that Einstein's equations are not even correct at the largest possible scale without the addition of a cosmological constant. For these reasons perhaps the work of Wheeler [65][66], Sorkin [27] and others in this area has not found mainstream support. In this paper an outline argument for an alternative explanation using 4-geons is proposed consistent with general relativity without a cosmological constant.

A further problem is that it is difficult to see how 4-geons could be compatible with the wave-particle duality of quantum mechanics.

The idea of geons, however, has not died. The work of Hadley [31][32][23][33][34] in defining 4-geons is an example. 4-geons are defined as geons with closed time-like curves, that is, time-loops. His work suggests that there may be a possibility of compatibility between 4-geons and quantum mechanics. Although he doesn't deal with wave-particle duality, the quantum logic he derives from 4-geons is compelling.

Interestingly, 4-geons presuppose a large-scale tendency towards 'causality' simply by virtue that only an appearance of large-scale causality is compatible with observation. By definition, 4-geons presuppose a small-scale breaking down of causality, since they possess time-loops in their structure. Thus, 4-geons are highly consistent with, and therefore arguably follow from, the two remarks in the section above, entitled "A Philosophical Discussion About Causality." Similarly, 'remark 1' and 'remark 2' are indicative of 4-geons. They could also have complex knot-like structures comparable with Amaral's 'entanglements' [1][2]. Some detailing of 4-geons follows.

Remark 4: A case for 4-geons follows from the discussion above, particularly when 'remark 1' and 'remark 2' are included. This, however, requires a reasonable explanation for 'dark energy,' assuming general relativity is not to be altered, or a cosmological constant added, and must carry the proviso of 'stability' with respect to any hypothetical wormhole-like solutions. A further proviso is that consistency with the wave-particle duality of quantum mechanics is difficult to imagine.

4-GEONS AND SPACE-TIME

The idea of 4-geons originated with Hadley [31][32][23][33][34] who, without demonstrating stability or even the existence of an example 4-geon, has shown that geons with closed time-like curves in their structures can behave like quantum particles within general relativity under certain conditions. In other words, geons modelled as wormhole-like structures with time-loops promise to explain some of quantum mechanics from within general relativity. He also notes that this applies to variants of general relativity.

The current author, also without dealing with stability, recently provided an example 4-geon solution [64] based on Hadley's definition, using an adaption of a solution presented by Hawking [38] and along the lines of Arcos and Pereira [3], that is, at each end of the wormhole there is a 'fast' Kerr-Newman singularity, reminiscent of an electron-positron pair. The example uses the open-endedness conjecture explained below.

N.B. Given that the stability issues may only be explainable by a unified theory, for example including strong and weak nuclear forces, or other restrictions as yet unknown, it is premature to discount 4-geons in light of the potential upsides.

Hadley's 4-Geons

Hadley's argument requires five axioms and a conjecture to be satisfied by a prospective 4-geon (below). With these he derives the possibility of quantum logic from within general relativity, a seeming contradiction, and therefore a powerful result.

Hadley's Conjecture 1: (4-Geon) A particle is a semi-Riemannian space-time manifold, M, which is a solution of Einstein's equations of general relativity. The manifold is topologically non-trivial, with a non-trivial causal structure, and is asymptotically flat (see axiom 1) and particle-like (see axiom 2).

Hadley's Axiom 1: (Asymptotic Flatness) Far away from the particle space-time is topologically trivial and asymptotically flat with an approximately Lorentzian metric.

Hadley's Axiom 2: (Particle-Like) In any volume of 3-space an experiment to determine the presence of the particle will yield a true or false value only.

Hadley's Axiom 3: (State Preparation) The state preparation sets boundary conditions for the solutions to the field equations.

Hadley's Axiom 4: (Measurement Process) The measurement process sets boundary conditions for the 4-geon which are not necessarily redundant in the sense that they contribute to the definition of the 4-manifold.

Hadley's Axiom 5: (Exclusive Experiments) Some pairs of experiments are mutually exclusive in the sense that they cannot be made simultaneously.

None of Hadley's axioms add anything new to general relativity beyond allowing closed time-like curves/ non-time-orientability. These axioms are constraints that if satisfied enable general relativity to be capable of performing quantum logic in the sense of an orthomodular lattice of propositions, as opposed to a Boolean logic. For a full explanation, see Hadley's work [31][32][23][33][34] (available online). Strictly, Conjecture 1 is not required, only the five axioms. In addition, other field equations could be substituted for Einstein's field equations with similar results, but as Hadley notes, it is compelling if 4-geons were solutions to Einstein's field equations, hence Conjecture 1. The 4-geon presented by the current author in [64] is shown in that paper to satisfy Hadley's Conjecture 1 and Axioms 1 and 2.

The Open-Endedness Conjecture

In order for the example 4-geon in [64] to satisfy the other 3 axioms, which are about measurement, a completely novel approach is adopted, involving 'open-ended space-times.' That these, or something very similar, correctly model reality is the *open-endedness conjecture*.

In "An Example 4-geon" [64] open-ended space-times are defined as follows:

[64] *Definition 4:* A space-time S(M; Λ) is the set M of four-dimensional Lorentz manifolds together with metric that are satisfied by a set Λ of boundary conditions upon that manifold.

[64] *Definition 15* (Open-Ended Space-Time): Any space-time that has an infinitely large set M of different possible manifolds is called an open-ended space-time.

The 'measurement process' and 'state preparation' as used in Hadley's axioms are then defined as the imposition of additional boundary conditions on M, such that the resultant set is still an open-ended space-time. This means that known past features of a causal space-time must be common to all members of M. Some features, however, can remain statistical in that they appear in some members but not all.

This is then enough to derive the last three of Hadley's axioms and an example 4-geon results!

It is interesting to note that the open-endedness conjecture is formally a tighter restriction on space-time than general relativity, without any causality constraints. Therefore 4-geons can exist within general relativity.

4-GEONS AND DARK ENERGY

'Remark 4' identifies 'dark energy' as a potential problem with the argument for 4-geons, assuming general relativity is not altered. So armed with the concept of 4-geons, how might 'dark energy' be accounted for?

'Dark energy' first of all is a supposition, a supposition used to explain a recent observational result that the expansion of the universe following the Big Bang appears to be accelerating [48][14]. A search for 'dark energy' on xxx.lanl.gov will quickly show the size of this field as an area of investigation. Mathematically, 'dark energy' is often modelled as a constant added to Einstein's field equations of general relativity, called the cosmological constant. This is a new version of the cosmological constant first hypothesised by Einstein in an attempt to balance gravity with a repulsive force so as to create a static universe. He famously referred to this as his 'biggest blunder' [56] because it blinded him to the possibility of a dynamic universe and a prediction of the Big Bang. There are many other possible explanations for the accelerating expansion.

The problem, of course, is that dark energy has not yet been directly detected as of the time of writing, and certainly appears not to interact with electromagnetic fields, hence the adjective 'dark.'

So how can 4-geons help?

The example 4-geon provided in [64] as already mentioned makes use of a wormhole-like structure along the lines of Arcos and Pereira [3]. In the case of Arcos and Pereira's model, one mouth of the 'wormhole' appears as a negatively charged particle inducing curvature in space-time with positive gravitational force and the other mouth has positive charge and a 'negative' curvature producing gravitational repulsion just as dark energy is supposed to do, but with the same amount of negative mass in the second particle as the first particle has positive mass. These particles are shown to be enticingly compatible with electron models, and with some added assumptions [3][8] actually lead to the Dirac equation, or quantum electrodynamics model of the electron!

The naïve argument is, therefore, to call the first mouth an electron, and the second mouth a positron, regurgitating the old hypothesis that in addition to inverted charge, anti-matter may be gravitationally repulsive. This however, does *not* explain dark energy, since the charge interactions of the anti-particles would be detectable.

Further the existence of concentrations of 'negative mass' in particle-like chunks, as would be the case under this model, would be contradictory to the dominant energy condition [38][55][16][62], which implies via the positive mass theorem [38][55][16][62] that asymptotically flat (i.e. particle-like) solutions with negative energy/mass are contradictory to causality. Energy conditions, as with time-orientability, are restrictions made to general relativity that are made from time to time by physicists keen to exclude unrealistic and unreasonable space-times from consideration. In this argument the dominant energy condition is justified by its close proximity to the weak energy condition, which is in turn closely connected with causality [38][55][16][62], and therefore is reasonable, or even predicted, under 'remark 1' above. But under 'remark 1' the key difference to normal assumptions is that it does not need to be absolutely true, only approximately so, or true at certain limits.

The idea of 4-geons offers another explanation as to what dark energy may be. The explanation depends on the (mathematically misleading) idea that in general relativity negative masses behave in a similar way to positive masses, but as if time were reversed. Unfortunately, this is a misleading heuristic and so needs explanation. Negative masses have never been observed, and are believed not to exist on the large-scale by most theorists, since they tend to lead to behaviours that contradict the laws of entropy and thermodynamics. Nevertheless, Einstein's field equations are consistent with negative mass solutions, and these will be used here. Positive mass black holes in the vicinity of each other will, all other things being equal and excluding perfect orbits, tend to coalesce into bigger black holes under the force of gravity. Reverse this idea in time and you have a 'white hole' that repels everything. The possible solutions are also consistent with 'white holes' emitting matter and then repelling that matter, just as black holes attract and swallow matter. No 'white hole' has ever been observed, and it would contradict causality and the laws of thermodynamics. The reason for this is that there is no rule to say what and how the 'white hole' emits; any solution may be possible, leading to solutions where causality breaks down, or rather only works in reverse. That is the sense in which time is reversed with negative mass solutions.

The Schwarzschild solution is the most used large mass (and 'black hole') solution to Einstein's field equations:

$$ds^2 = c^2\left(1 - \frac{2GM}{c^2 r}\right)dt^2 - \left(1 - \frac{2GM}{c^2 r}\right)^{-1}dr^2 - r^2 d\Omega^2$$

where G is the gravitational constant, M is interpreted as the mass of the gravitating object, and

$$d\Omega^2 = d\theta^2 + \sin^2\theta d\phi^2$$

As is well known, it remains a solution even when the mass M is negative. This is the best-known solution to Einstein's field equations, and outside of a body of mass, or even inside a black hole the solution has the property of being Ricci flat, and it is also spherically symmetrical.

It can be shown that negative mass Schwarzschild 'white holes' and negative masses generally would gravitationally repel everything, positive and negative masses alike, and that positive masses gravitationally attract everything, positive and negative masses alike. To avoid this conclusion it would be necessary to separate the concepts of inertial mass from gravitational mass. However, this is not supported by the construction of mass out of space-time geometry as modelled here (see above "Geons and Space-time"). Whilst this may be counter-intuitive in the sense that negative and positive masses behave asymmetrically, contrary to positive and negative charges in electromagnetism, it nevertheless follows from the different treatments of mass and charge in the equation of general relativity. That this is the case is shown in [10] and applied in [20].

The essential idea can be shown using the Newtonian physics limit of general relativity, where m is the mass of a test object in the gravitational field of the large negative or large positive mass **M**.

$F = ma$ and $F = GmM/r^2$

Simple algebra yields the acceleration on the test particle caused by the gravitational field of the large body (assuming gravitational and inertial masses are equivalent):

$a = GM/r^2$

The acceleration a depends on the sign of M. If the M is positive, the acceleration is towards the large body (gravity); if M is negative, the acceleration is sign-inverted and therefore away from the large body (repulsion by a negative mass). Since there is no mention of the test particle mass, this acceleration is the same as Galileo discovered for feathers and bricks and, according to this model, for negative masses.

Only non-asymptotically flat solutions will be generally admissible under the energy conditions mentioned earlier. This is a constraint that can be imposed on 'white hole' solutions so as to maintain some consistency with causality at the large-scale; we must imagine 'white holes' fragmenting in such a way that this constraint is satisfied. 'White holes' may be possible after all.

To show that such a fragmentation is feasible, it is only necessary to consider two 'white holes' at some distance from each other in a state of mutual repulsion and accelerating away from each other, with the assumption that any other emissions or fragmentations are on hold. We can (all other things being equal) set our boundary conditions to explore a solution, so we can set the velocities of the 'white holes' to be such that, if we run a mathematical simulation backwards along the time axis, the two 'white holes' must have been at the same point at some earlier position in time. Since it is difficult to pass into a 'white hole,' in the same way that it is difficult or impossible to escape a black hole, such a time reversed collision can only represent a fragmentation of the 'white hole,' that is, a mutual emission: the two 'white holes' spitting each other out.

It is easy enough conceptually to get non-asymptotically flat solutions simply by imposing that the emissions from a 'white hole' consist only of parts of the 'white hole' itself, and in such a way that it tends towards a homogenous 'dark energy.' This would be a complete disintegration. 'White holes' would therefore not exist as truly distinct entities under this hypothesis.

When would the process of fragmentation stop? Well the answer is that it doesn't need to stop; 4-geons can be defined as small as required, ad infinitum, or for consistency with quantum mechanics, down to the Planck scale, reminiscent of quantum foam [60], not to mention vacuum energy and even the archaic concept of ether! The various fragments would tend to push away from each other and separate under their own negative gravity, creating a near-homogenous 'dark energy.' This could be consistent with the dominant energy condition by virtue that the solution is necessarily spread out and homogenous, that is, it is not asymptotically flat.

An example of a different, but related, infinitely splitting solution can be found in [12], showing that infinite splitting is feasible.

What would govern the velocities of emission and rate of fragmentation? No idea! Nor is it necessary to specify it for the purposes here: anything consistent with the equations would be acceptable with respect to this argument.

So at one end of the wormhole, imagine a charged fundamental particle, for example an electron, with positive gravitational force, and at the other, a solution to Einstein's equations (without cosmological constant) that consists of an almost infinite number of smaller 'particles' fragmenting and filling space ad infinitum, or at least until the Planck scale, into a near-homogenous 'dark energy.' The asymmetry of the dominant energy condition could therefore explain why particles exist and have positive mass, and at the same time explain why dark energy is 'spread out' and not identifiable as individual particles.

The 'dark energy' would have a repulsive gravitational effect by construction since it has the negative mass counterparts to the positive mass particles. The failure of dark energy to interact with electromagnetic fields would be explained: as a near-homogenous negative mass it would be charge neutral, because everyday positive matter, on average, is charge neutral. By virtue of near-homogeneity, any particle oscillations or annihilations would in principle be cancelled out by other particle oscillations or creations instantaneously. And the asymmetry between matter and dark energy under this hypothesis could also explain why it doesn't 'annihilate' in contact with matter as anti-matter particles [51] do.

N.B. Whether anti-matter particles have positive or negative mass is not relevant here.

A detailed mathematical derivation, or proof, that solutions of this type could be made exact within general relativity may well be possible, as also may a mathematical disproof of the possibility. But given that three body problems are hard to calculate in Newtonian physics, and given that exact solutions to general relativity are notoriously difficult to discover, it remains beyond the scope of this paper to solve a near-infinite body problem with exactitude in general relativity, even as a 'limit' type mathematical problem. The arguments rest as heuristic, even though they do need a mathematical foundation to be progressed further. Perhaps multiple black hole solutions [11][13] could be extended to such a 'limit'?

Testable Hypothesis

Whilst the difficulty in making these arguments rigorous is clear, some testable predictions of this hypothesis can nevertheless be stated by virtue of simple reasoning:

(i) Contrary to current expectations that 70% of the universe is dark energy. This hypothesis suggests that the amount of normal matter, probably including dark matter, should be equal to the amount of dark energy. So a figure close to 50% for the energy distribution of dark energy in the Universe should be the case rather than the current 70% figure. This dark energy then serves to cancel out the positive mass/energy distribution from galactic or positive matter and energy, i.e. particles. Such an assessment probably needs dark matter to be better understood [51] [35] and the gravitational constituents of the Universe to be detailed experimentally. It may also require an assessment of contributions from radiative energy.

(ii) Dark energy would remain undetectable directly by electromagnetism due to homogeneity and, therefore, net neutral charge.

(iii) Assuming the positive mass/energy of the universe is constant or near constant, the dark energy of the universe would also be constant. So that as the universe expands, the density distribution of dark energy would thin, and thus the repulsive contribution of dark energy to this acceleration would be decreasing with time. This thinning of dark energy should result in a slowing of the acceleration of expansion as the Universe expands at least in the time period following the relative stability of mass distributions after galaxy formation. The assumption of a constant rate of acceleration of cosmic expansion would be wrong. The reality of the expansion of the Universe and the Big Bang would therefore be more complicated than currently envisaged. The model does not necessarily lead to a younger Universe, as might be guessed, as interactions between matter and dark energy prior to galaxy formation can not be guessed and may even have formed stable states or periods of contraction.

Further, interactions between dark energy and matter consistent with this model may be observable astronomically, for example, if dark energy retards the passage or creates a drag on matter passing through it at near-light-speed velocities. However, it is neither clear to what extent this would be true with this model nor how to separate such results from other models of dark energy that could predict similar observations.

If accurate, the dark energy/4-geon hypothesis would mean that Einstein's field equations need no cosmological constant or alteration after all in order to be consistent with cosmological observation. However, the mathematical tools for dealing with the situation of near infinite topological complexity would need to be developed, and approximations might well need such additions as a cosmological constant or similar for practical purposes in any case.

Remark 5: A heuristic explanation for dark energy has been given. It is heuristic because it lacks mathematical rigor, although it has been indicated how mathematical formalism might be achieved. The explanation does, however, have predictive power, and therefore has merit as a testable hypothesis. It does, however, represent quite a radical perspective. It is essentially consistent with, and even uses, the energy conditions.

Whilst writing up this paper, the following paper became available: "Classical Dark Matter," again by Hadley [35], wherein he proposes an explanation also for cold dark matter in terms of 4-geons. However, what are really needed here are experimental results. An upward estimate of the contribution of matter or dark matter in the universe or a downward estimate of the contribution of dark energy would be consistent with the predictions here, but these must be made on the basis of observation rather than as a theoretical device. A changing rate of universe expansion would also be indicative – so that the cosmological constant would be a variable rather than a constant, and all other things being equal, the acceleration reducing with expansion. Inconsistency of experimental evidences with respect to the age of the Universe would also be indicative.

A quick end to this speculative model could be achieved if dark energy is simply observed to be something else entirely and the ideas presented here proven wrong!

A thorough mathematical analysis of this dark energy model would intuitively lead to a classical counterpart of the Casimir effect, an external pressure currently modelled by quantum field theory that exists between two large parallel uncharged plates. If such a theoretical analysis could be completed, with the correct parameters for the Casimir effect resulting, the existence of the Casimir effect itself could already be direct laboratory experimental evidence for this model. As yet, the mathematics is lacking, and no such evidence can be claimed.

Time-scales for direct experimental verification or disproof depend on many factors, but new understanding of the gravitational make-up of the Universe is most likely to come from laser interferometry experiments such as LISA,[1] where gravitational waves can in theory be observed directly by lasers linking satellites placed in orbit around the Sun.

If radio and visual telescopes are the 'eyes' of humanity in space, laser interferometry and gravitational wave detection could be its 'ears.' As of yet, nobody has directly detected gravitational waves, so it is difficult to say how quickly it could change our perceptions of the Cosmos. However, without this data, in my opinion, we will remain unaware of many otherwise observable phenomena, and in the final analysis be significantly slowed in any experimental exploration into the nature of dark energy.

Whether current or soon to be available astronomical data (such as the recent measurements of likely distributions of dark matter) could also provide evidence for or against any of the above predictions is an open question.

[1] http://lisa.jpl.nasa.gov/gallery/ligo-lisa.html Accessed April 26, 2007.

A HEURISTIC EXPLANATION FOR TIME

So, taking the open-endedness conjecture, is it possible to explain the large-scale appearance of causality, and therefore the approximate validity of the energy conditions mentioned in this paper and all that follows from these without making such a constraint at the small-scale? Further, can entropy and the so-called ‘arrow of time’ be given explanation within this hypothesis?

The answer to both of these questions is ‘yes,’ but only provisionally and heuristically. That is conceptually, in outline.

Under the open-endedness conjecture, space-time would be an infinite set of possible space-times. We would have no idea which one of these the Universe actually was, or even whether such a distinction has meaning. A measurement, by definition, would be a selection of a subset of this set, that is, a narrowing down of the infinite set of possible space-times. We would never reach the classical limit of exactly one space-time under this definition of measurement. To understand the mathematical structure of the open-endedness conjecture, see [64].

In order for a probability distribution to be placed on outcomes of experiments as occurs in quantum mechanics, it would be necessary for these open-ended space-times to carry with them probability distributions, and for them to carry a probability measure. There is no obvious way to do this. But given such a probability distribution, we can speculate that certain features of space-time will be present in larger ‘densities’ than others and that certain features would be preferred by the distribution.

That certain distributions of matter and energy in space-time maximize ‘entropy’ is well known, and the laws of entropy, thermodynamics, have their counterparts in both classical and quantum mechanics. Essentially, entropy is the idea that when you shuffle a deck of cards, the probability of seeing an obvious pattern in the outcome is low, since the obvious patterns, by definition, represent a small subset of the outcomes. This presupposes a certain ‘fairness’ in the shuffling, which is contrived by the shuffler. In thermodynamics the universe proceeds from low entropy to high entropy, generally, with time. This presupposes two conditions: (i) That there is a measure by which entropy is calculated (in the case of a pack of cards by permutations), plus that the shuffling is ‘fair’; and (ii) that early in time the universe starts in a low entropy state [54], which implicitly also presupposes ‘time’ and some sort of large-scale causality. The arrow of time, according to entropy, is nothing other than the ‘shuffling of the deck’ in the analogy above.

Now, looking at this from the point of view of open-ended space-times, and a hypothetical probability distribution over them, we can start to talk about the probability distribution in terms of ‘fairness.’ ‘Fairness’ in this context becomes simply an indifference within the probability distribution to the detailed distributions of matter and energy in any particular time-slice, combined with condition (ii) above. That is, it represents a certain lack of specification in the probability distribution.

Remark 6: Entropy follows from large-scale causality (see ‘remark 1’) and a certain lack of specification or ‘fairness’ in the probability distribution of open-ended space-times. It also requires a low entropy ‘initial’ state. The measure of entropy for any state is defined in terms of the deterministic system governing those states.

So this is really a 'lack' of a criteria rather than a constraint. Now the low initial entropy state and large-scale causality need to be explained.

An answer to the appearance of 'large-scale causality' itself follows heuristically, using an extension of the idea of entropy. The idea is that those features (meaning any 'physical event,' 'outcome,' topological or geometric feature) that have the highest probability, and that therefore have the highest density in the probability distribution, will correspond to those features that are featured within the highest 'number' or 'density' of possible space-time manifolds. And that somehow the probability distribution counts space-times in a 'fair' way in some sense analogous to the 'fairness' or equality of outcomes seen in the shuffled deck of cards example. As it were: 1 space-time, 1 vote. The problem is that you cannot count infinite numbers of objects without a formal measure constructed over them to impose and measure this 'fairness.' The pack of cards, as the analogy goes, is infinite. The construction simply can't be done without grouping them together in certain ways called 'measures.' The argument here, therefore, lacks formality and remains a heuristic argument until such a 'measure' can be constructed.

Remark 7: Imposing 'fairness' on open-ended space-times requires a 'measure' to impose this 'fairness.' Mathematically, this is likely to be difficult, as the number of space-times involved is infinite, and there isn't an obvious way to construct such probability measures.

So armed with this heuristic level concept of 'fairness,' we proceed as follows, and ask what type of manifolds, or rather what features, might be the most 'densely' represented in the probability distribution?

One answer could be those features that can be used freely and generically within manifolds whilst keeping the degrees of freedom for the rest of the manifold as large as possible. Those features would then appear in a very large number of possible manifolds. This is analogous to tessellation, where the tessellation pattern is allowed to change without the overall tessellation-effect breaking down. There would be some restrictions to the possible patterns allowed, some sort of large-scale dependency, carried along through the layers, changing subtly depending on the shapes used in the previous layers, but constraints on small-scale features would be quite different and subject to more local restrictions.

Definition: We can call this type of heuristic argument, this principle of maximal occurrences, *a generalized entropic argument*.

Simply put, this could be done if the most densely represented manifold features were built out of layers, where each layer was related to, but not entirely dependent on its neighbours. The local variation in pattern would be analogous to the randomness of quantum mechanics, and the large-scale dependencies and the layer structure itself would be analogous to large-scale causality. The layer structure, under the hypothesis, would maximize the number of compatible space-times and hence the density of the associated features in the distribution. The (3,1) signature of the Lorentz manifold would also, under this hypothesis, naturally lend itself to a structure where the 'odd one out' dimension, i.e., time, would be associated with this layer building and therefore 'large-scale causality.'

Remark 8: Large-scale causality and small-scale lack of causality could therefore be a result of statistical effects in the selection of open-ended space-times, according to a 'fair' probability measure of 'remark 7.'

A 'fair' probability measure ('remark 7') could therefore lead to large-scale causality ('remark 8') which in combination with a low entropy initial state ('remark 6') would lead to the appearance of entropy in physical laws.

This leaves only the low-entropy initial state to be explained. The answer to a low-entropy initial (or at least 'early') state also follows, heuristically, using a similar generalized entropic argument:

Given a region of a manifold (or open-ended space-time) manifesting large-scale causality, then any time-slice in a slightly lower entropy state to another time-slice would be adequate (via remarks 6, 7 and 8) to lead to the laws of entropy. The arrow of time is therefore defined in terms of the direction from the lower to higher entropy time-slice.

The generalized entropic argument then applied is that the largest number of variations of manifolds compatible with such a region occurs when the region is allowed to continue backwards along the layer structure approaching zero entropy, and forwards along the layer structure approaching infinite entropy. That is, having a lower or upper bound for future or past time-slices is unnecessarily restrictive, restricting the number of compatible space-times and therefore the 'density' of such restricted space-times in the probability distribution. Time and the arrow of time result.

Remark 9: Generalized entropic arguments can heuristically account for the existence of time, the arrow of time, large-scale causality, small-scale lack of causality, the appearance of entropy in physical laws, and a low-entropy initial or 'early' state. The arguments require a 'fair' probability measure over open-ended space-times.

Defining 'fair' is the catch; without such a definition these arguments remain heuristic.

A SUMMARY INCLUDING THE CONNECTION BETWEEN 4-GEONS AND CAUSALITY

(1) In the section above, entitled "A Heuristic Explanation For Time," it was shown how the open-endedness conjecture and generalized entropic arguments relating to a 'fair' probability distribution over open-ended space-times can account for the appearance of large-scale causality and entropy, including a low-entropy initial state. This large-scale causality also requires small-scale acausality.

Under the open-endedness conjecture, space-time would be an infinite set of possible space-times. A measurement, by definition, would be a selection of a subset of this set, that is, a narrowing down of the infinite set of possible space-times. In order for a probability distribution to be placed on outcomes of experiments, as occurs in quantum mechanics, it is necessary for these open-ended space-times to carry a probability measure. There is no obvious way to do this. But given such a measure, we can speculate that certain features of space-time will be present in larger 'densities' than others and that certain features would be preferred by the probability distribution. An answer to the appearance of 'large-scale causality' then follows *heuristically*. The idea is that those features that have the highest probability, and that therefore have the highest density in the probability distribution, will correspond to those features that are featured within the highest 'number' or 'density' of possible space-time manifolds. The result will be those features or space-times that possess the highest number of permutations – analogous to shuffling a pack of cards, this assumes a 'fair' probability distribution. On the large-scale, this heuristic suggests that space-times could be 'layered' so as to allow the largest number of permutations. This assumes local variations are permitted within the layers, since if each layer is identical, the number of permutations for the system reduces to 1. Therefore, small-scale acausality is required for large-scale causality to occur.

This is analogous to saying that there are more permutations of apartments in a multi-floored tower block, than in a three storey building with the same land area. This assumes locally each apartment is allowed to be different and represents a variation. If each layer or apartment is exactly the same – then the number of permutations would suddenly drop to 1. Maximum permutations are obtained by allowing maximum local variation coupled with the largest number of apartments, and hence the largest number of layers or storeys, with whatever shared structure is needed to maintain the building. This naturally corresponds to causality and time – causality is analogous to the infrastructural homogeneity and predictability of each apartment's most general features (structural beams, general shape and size constraints, central lift shaft in the same place for all storeys, monotonic reduction of pipe diameter as the altitude increases, and so on), and local acausality, for example, in the completely free choice of the colour of the bathrooms, the fairly free layout of the apartment, and minor variations in floor area. Large-scale causality, plus small-scale acausality, equals maximum permutations. Maximum layering (a tower block with infinite storeys) is then analogous to a time axis.

(2) Acausality in general relativity is associated with closed time-like curves or time-loops. Generally, these are created by topological distortions in space-time such as wormholes. Due to the constraints of large-scale causality, wormhole like features in space-time would need to be small and particle-like, with closely connected mouths, or otherwise structured to prevent large-scale causality breaking down completely. Note that here large-scale causality is a matter of degree, not an absolute; it is a strategy that has been argued maximizes the permutations in the probability measure. It is of statistical origin. The structure of particles is here presented slightly differently from the simple wormhole idea: that whilst one end of the wormhole represents a particle, the other (negative mass) end becomes topologically highly complex and fragmented, so that the overall structure more resembles a 'hydra' than a 'wormhole.' The particle end of the hydra model is the 4-geon, the tentacles end of the hydra is dark energy.

This leads to the idea of the Cosmos as topologically multiply connected with many hidden interconnections, perhaps providing a classical explanation for quantum entanglement.

(3) The relationship between 4-geons and causality is equivalent to that between small-scale acausality and large-scale causality. They are both consequences of the open-endedness conjecture with heuristic arguments. They are related to each other, under this hypothesis, in that 4-geons create the 'slack' in the system that allows causality at the large-scale to maximize permutations and therefore appear as a consequence of a generalized entropic argument. This is perhaps analogous to a mechanical device whose parts must be separated by very small spaces, the 'slack' in the system, that allows transmission of oil and movement between the otherwise deterministic parts.

(4) Thus, 4-geons allow for the interpretation of mass and charge as topology within a reduced version of Einstein's field equations unifying mass, energy and space-time. Charge is also sourced in the topology of space-time under this interpretation.

THE OPEN-ENDEDNESS CONJECTURE AND FREE WILL

So, coming back full circle from philosophy to science to philosophy, what might the open-endedness conjecture predict about 'free will'?

The answer is simply that 'free will' as a narrowing down of the infinite set of possible space-times M would be, objectively, nothing other than a measurement! A decision to enact an experiment and its subsequent performance is no different under this model than a measurement obtained from an experiment. This makes sense in that only by doing the experiment can the process of doing the experiment be observed, but something subjective, 'intent,' is completely missing from the model.

This lack of meaning given to 'intent' is perhaps paradoxical, but the paradox is that the construction deals only with objective consequences; it is an objective construct and can say nothing about subjective content. The subjective is conspicuous by its absence; it is paradoxical because the subjective content of an intention or choice is modelled no differently from a passive observation. Under this hypothesis subjective 'intent' is without mechanism; the model can say nothing about it, only about the objective results. Tautologically, for the subjective to be something other than mechanism, it must, as it were, be something else, and in this sense has become conspicuous.

On the other hand, with a complete model that includes quantum mechanics and probability distributions for the infinite sets of possible space-times M, perhaps it would be possible, under this hypothesis, to probe this question further; the arguments of quantum mind (and even quantum mysticism) could be empirically tested if certain probability distributions varied from expectation under 'subjective' circumstances, for example, 'free will.' But for this to be done, subjective experiences would have to be considered as observations. This leads to subjective empiricism.

The distinction between objective and subjective is given some foundation by the current author in [63]. The differences between objective science and subjective observation are also discussed in [67].

CONCLUSION

Amaral's paper on the feasibility of time-travel [1], Hadley's 4-geons [31][32], and the current author's open-endedness conjecture [64], along with philosophical and physical arguments are used to present a radical view of space-time that provides a heuristic-level topologically complex model of dark energy with testable predictions. The model connects an explanation for positive mass particles in terms of topology to a near-homogenous distribution of negative mass dark energy. The paper also presents a heuristic explanation for the large-scale causality, the arrow of time, time asymmetry, and with provisos, the energy conditions. The explanation for large-scale causality is not dependent on the dark energy model. Mass and charge are also argued to be sourced in topology enabling classical physics to be reduced to an open-ended set of (non-null) source free electro-vacuum solutions with ‘fair’ probability measure, where ‘fair’ was only conceptually outlined. This reduction of the classical limit (similar to the approach of Rainich, Misner, and Wheeler [65]) may be more suitable for unification with quantum mechanics, and contrary to appearance, the resulting topologically complex classical model remains a subset of general relativity without cosmological constant – where general relativity is defined in the broadest sense without any causality or topological constraints. The model exhibits quantum logic in its structure due to the presence of 4-geons. This model conceptually unifies mass and energy with space-time itself; charge is also interpreted as a product of topology, and therefore also of space-time. The heuristic arguments presented in this paper demonstrate that this is reasonable.

Causality in this paper is divided between two limits: (i) large-scale causality, and (ii) small-scale lack of causality. This is necessary because the large-scale of classical physics appears generally causal, and the small-scale of quantum mechanics manifests acausality, quantum mechanics being random in well defined respects. How to deal with this *a priori* scale difference is inferred from the existing evidence of classical and quantum physics respectively in the philosophical discussion section, and the conclusions of that discussion are used as inputs or assumptions for the physical model. The end result is a model that manifests small-scale acausality and large-scale causality, compatible with both quantum and relativistic physics. What is more, both of these limits are required in order to maximize permutations in a generalized entropic argument, so that they become two sides of the same coin.

A fully rigorous mathematical proof or disproof of some or all of these ideas within general relativity may be possible, but this leads to significant mathematical complexity. This model also leads to testable physical predictions. However, there are also significant problems in making physical tests due to lack of current technology for directly measuring the gravitational structure of the Universe.

A proviso throughout this paper is that only some quantum behaviours have found explanation,. Other behaviours, such as wave-particle duality, remain at odds with the particle model presented here. There is also no consideration of weak and strong nuclear forces in this paper. Other provisos include the stability of 4-geons, which has not been proven, the lack of definition of a ‘fair’ probability measure over open-ended space-times, and other small, but reasonable, assumptions.

Many other steps to bring general relativity and quantum mechanics closer together will be needed before an attempt at unification. Nevertheless this paper has shown that there are more possible paths to unification than are generally considered, and that the approach described here, though radical, is quite natural empirically and philosophically.

The open-endedness conjecture and 4-geons coupled with the concept of a ‘fair’ probability measure has been shown to have a great deal of explanatory power.

> *Riemann has shown that as there are different kinds of lines and surfaces, so there are different kinds of space of three dimensions; and that we can only find out by experience to which of these kinds the space in which we live belongs. I hold in fact*
> *(1) That small portions of space are in fact of a nature analogous to little hills on a surface which is on the average flat; namely, that the ordinary laws of geometry are not valid for them.*

(2) That this property of being curved or distorted is continually being passed on from one portion of space to another after the manner of a wave.
(3) That this variation of the curvature of space is what really happens in that phenomenon which we call the motion of matter, whether ponderable or ethereal.
(4) That in the physical world nothing else takes place but this variation, subject (possibly) to the law of continuity.

William Clifford, 1876 [18]

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