

WHY IS THERE LIFE?

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ABSTRACT: Ongoing theoretical explorations and experimental research on the origins of life focus predominately on the details of how life evolved. However, there remains an intriguing second-order question one step removed from these focused investigations. That is: Why is there life? Exploring the forces, mechanisms, and physical laws (and their interactions) that define the creation of animate out of inanimate matter is both theoretically interesting and useful to understanding the biological and philosophical nature of life. Defining the key factors (“effectors”) behind the creation of life opens a fertile field of possibilities that is as yet incompletely explored.

The discussion of these effectors in this manuscript helps to advance our understanding of why there is life by elucidating the motive force behind the creation and evolution of life throughout the universe and by giving insight into life’s apparent teleonomy and other unique characteristics. The results of these effectors, working in conjunction with the electromagnetic force, are summarized. Similarities in the evolution of animate and inanimate complex matter are explored to explain why life evolves in the universe. Characteristics considered unique to life (creation, metabolism, growth, reproduction, evolution, ‘self’ and the logic of the metabolic machinery, together “teleonomy”) are explained employing an expanded definition of complexity applicable to both sides of the animate-inanimate divide.

KEYWORDS: Science; Philosophy; Creation of Life

INTRODUCTION

The traditional approach to the origin of life has focused on how life first emerged and later evolved, and where and when the transition from inanimate to animate matter occurred. Advances in our understanding of the biochemistry of life’s origins continue

in experimental laboratories around the world.^{1,2} The thermodynamic consistency of increasing organic complexity and proven or theoretically possible scenarios for a host of prebiotic constructions leading to advancing organic complexity have been proposed.^{3,4} Theories have been suggested to explain the creation of advanced prebiotic chemistry and its transition into life.⁵ Such theories for the origin of life are categorized as either bottom-up or top-down.⁶ An extensive literature has developed over the past century for the bottom-up school, which builds on the gradualism of increasing organic complexity.⁷ The equally plausible top-down approach, conversely, envisions the sudden emergence of animate matter upon the attainment of critical levels of certain interacting molecules that resulted in autopoietic systems.⁸ Crucially, what all these theories share is a *recognition that complexity advances*. Although there is no certainty regarding the level of organic complexification reached on the prebiotic earth, organic complexity advanced markedly with the transformation to animate matter. This tendency of increasing complexity frames the discussion below.

¹ Regis, Ed, *What Is Life? Investigating the Nature of Life in the Age of Synthetic Biology*, New York, Oxford University Press, 2008, p.11.

² Regis, *What Is Life?*, pp. 16-17. (Much is being learned of the basic nature of life through ongoing research. Uncertainties persist, such as the plausible pathways for the construction of advanced informational polymers of nucleic acids).

³ Artigiani, Robert. 'History, Narrative, and Meaning', *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 3, no. 1, 2007, p. 3.

⁴ Zubay, Geoffrey, *Origins of Life on the Earth and in the Cosmos*, 2nd ed., San Diego, Academic Press, 2000, pp. 188-190.

⁵ Smith, John Maynard, Szathmary, Eors. *The Origins of Life, From the Birth of Life to the Origins of Language*, Oxford, New York, Oxford University Press, 2009, p. 5. Examples include life originating in an iron-sulfur world. Hansma, Helen G, 'Possible origin of life between mica sheets', *Journal of Theoretical Biology*, vol. 266 no. 1, 2010, pp. 175-188. The primordial sandwich theory. Oro, John, 'Historical Understanding of Life's Beginnings', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, Berkeley and Los Angeles, University of California Press, 2002, p. 17. The clay template theory. Lane, Nick, *The Vital Question. Energy, Evolution, and the Origins of Complex Life*, New York, W.W. Norton & Company, 2015, pp. 134-135. Life originating in deep-sea alkaline vents. Gilbert, Walter, 'The RNA world', *Nature*, vol. 319, 1986, p. 618. The possibility an RNA based early biotic world that allowed a single molecule to function as an informational repository and a catalyst for the construction of advanced polymers offers a solution to the replication first versus information first conundrum.

⁶ Luisi, Pier Luigi, *The Emergence of Life. From Chemical Origins to Synthetic Biology*, New York, Cambridge University Press, 2010, p. 243.

⁷ Zubay, *Origins of Life on the Earth and in the Cosmos*, Part III Biochemical and Prebiotic Pathways: A Comparison, Chapters 22, 23, 24. Theoretical and real advances are being made in the prebiotic and early biotic pathways for the construction of carbohydrates, nucleotides and amino acids and their polymers, and lipids. Research into the biochemical evolution of systems chemistry in the formation of the main energy producing pathways for metabolism, photosynthesis, and the genetic code continue.

⁸ Kaufman, Stuart, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, New York, Oxford University Press, 1995, p. 4.

WHY IS THERE LIFE?

There is an additional question pertaining to origins of life research to add to the inventory of how, when, and where life arose. That question is: Why is there life? The motive force behind why advancing complexity should occur remains uncertain, but when elucidated will add greatly to our understanding of life. Comprehending why life must evolve from inanimate matter by exploring the nature of the forces, mechanisms, and possible laws impacting the creation of life will enhance our understanding of what life is in the broadest context. As we continue to develop our knowledge of how life may have arose and what life is, why there should be life is becoming a focus of attention.

However, uncertainties persist whether the ‘why’ question can be answered. Parenthetically, William Schopf wonders if the ‘why’ question should remain within the realm of philosophy and religion.⁹ Stanley Salthe has proposed the purpose of life can be understood through dissipative energy gradients but has concerns about the nature of the transition.¹⁰ Christian de Duve ponders whether we will ever succeed in explaining the origin of life naturally or, even, whether this phenomenon is naturally explainable before affirming it will be discovered within the natural world. However, he claims as long as the problem is not solved, the tendency to invoke ‘something else’ will subsist.¹¹ The vague, persistent awareness there may be something more to comprehend about life’s origins, complexity, and purposeful nature continues to permeate the literature.¹²

⁹ Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 1.

¹⁰ Salthe, Stanley N., ‘Energy and Semiotics: The Second Law and the Origin of Life’, *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 1, no. 1, 2005, p. 140. Stanley Salthe remains concerned that the “. . . lack of knowledge about the origin of the genetic system [is] so profound that it might as well be supposed to have been a supernatural event”.

¹¹ de Duve, Christian, *Life Evolving. Molecules, Mind, and Meaning*, New York, Oxford University Press, 2002, p. 51.

¹² Luisi, *The Emergence of Life*, p. 36. In 2006 Pier Luigi Luisi pines in his book “*The Emergence of Life*”, “. . . still something important is missing” in the transition to complex life. Schrodinger, Erwin, *Schrodinger. What is Life?*, Cambridge, Cambridge University Press, 2012, pp. 68, 8. Erwin Schrodinger considering Delbruck’s general picture of the hereditary substance notes that, “. . . living matter, while not eluding the ‘laws of physics’ as established up to date, is likely to involve ‘other laws of physics’ hitherto unknown . . .” He further declares: “We must be prepared to find a new type of physical law prevailing in it,” i.e., living matter. Venter, J. Craig, *Life at the Speed of Light, From the Double Helix to the Dawn of Digital Life*, New York, Viking, 2013, p. 45. Craig Venter remarks in *Life at the Speed of Light*: “Finally we should consider what ultimately drives all the frantic activity and turnover within each and every cell”. Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 168. In 2000 Geoffrey Zubay declares, “. . . new principles governing chemical evolution are to be discovered”. Thaxton, Charles B., Bradley, Walter L., Olsen, Roger L., *The Mystery of Life’s Origin: Reassessing Current Theories*, New York, Philosophical Library, 1984, pp. 169, 146.

Is there something unique in the transition to animate matter or, is this ‘something else’ suggested by de Duve, simply a natural progression of advancing complexity as has been suggested by others.¹³⁻¹⁴⁻¹⁵ The overriding question arises whether this ‘something else’ inducing the transition to animate matter is a deterministic or contingent process.¹⁶ Stuart Kauffman opines: “Somehow, in some as yet mysterious process, the organic molecular diversity of this spinning globe has taken energy . . . and cooked itself up from simple atoms and molecules to the complex organic molecules we find today . . .” noting, “. . .we now seek to understand the wellsprings of this stunning molecular diversity.”¹⁷ Ultimately, why there should be life may be inexplicable. However, complexity has advanced in the universe and understanding why this is so is inextricably partnered to the question: Why is there life?

Answering why life evolves from inanimate matter subsumes the question: What forces, mechanisms, and possible laws direct the creation of life? Advancing complexity, inanimate or animate, is evident throughout the universe and usually requires input of

Charles Thaxton, et al, in *The Mystery of Life's Origin* published in 1984 are concerned because of the large quantities of configurational entropy work needed to be done that “. . . unless some hitherto unknown principle operated the availability of such work would have been negligible,” and that “. . . some organizing principle must have been involved”. Schopf, (ed.), *Life's Origin, The Beginning of Biological Evolution*, pp. 5-6. William Schopf remarks in 2002 that in spite of the overall picture of how life emerged, “. . . the search for deep knowledge of the processes involved, an understanding of the details of each step, is a work in progress”. Regis, *What Is Life?*, p. 27. Ed Regis contemplates in his book from 2008 *What is Life: “What was the driving force that made it go?”* Pross, *What is Life? How Chemistry Becomes Biology*, Oxford, Oxford University Press, 2014, pp. 117, 119. Addy Pross posits as recently as 2014: “The question of how purpose and function can manifest themselves spontaneously is a profoundly important scientific question and its resolution would help connect chemistry, representing the objective material world, with biology, representing the teleonomic world.” He also laments: “Non-equilibrium thermodynamics has not proved to be the hoped-for breakthrough . . . A physically based theory of life continues to elude us”. Kauffman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, p. 54. And finally, Stuart Kauffman opines in 1995 in his book *At Home in the Universe*: “By what laws, what deep principles, might autocatalytic systems have emerged on the primal earth? We seek, in short, our creation myth”.

¹³ Luisi, *The Emergence of Life*, p. 39.

¹⁴ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 183,189.

¹⁵ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 134-135.

¹⁶ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 108-110. (A deterministic process evokes a purposeful nature to life's creation. When the forces and processes driving this transition are understood, these forces and processes will more precisely define why there is life and, if on balance these processes are deterministic, by extension, life's teleonomy. Contrariwise, an entirely contingent event would seem to deprive life of a purposeful nature and a universal expression. Siding with a deterministic process, Addy Pross, in addressing the transition to animate matter employing systems chemistry, raises the question, as have many other scientists and philosophers, of the driving force for this transition).

¹⁷ Kauffman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, pp. 113-114.

energy into these dynamic kinetic non-equilibrium systems.¹⁸ Various forces, mechanisms, and possible laws playing a part in the creation of life in addition to the electromagnetic force should be considered. Furthermore, defining the complexification of matter in broad terms will be shown to facilitate our understanding of life's unique characteristics.

DIFFERENTIATING ANIMATE FROM INANIMATE MATTER: COMPLEXITY AND TELEONOMY

The most apparent contrast between animate and inanimate matter is animate matter's vastly advanced complexity.¹⁹ A second evident contrast is the drive and tenacity of animate matter to persist.²⁰ It is this unique aspect of life, i.e., its drive to persist, which causes the greatest philosophical conundrum, raising the question of whether life has purpose.

Why did life (a highly complex system of organic matter) evolve from less complex inanimate organic matter and why does animate matter demonstrate a tenacity to persist, grow, reproduce, and evolve? At the pinnacle of evolution this resilience to persist is manifested in our conscious desire to procreate and avoid death; the two strongest motives of which we are cognizant.²¹ To grasp the essence of this 'force' or its purposeful nature consider the DNA repair enzyme Uracil DNA glycosylase whose sole 'purpose' is to stride along a strand of DNA. When the repair enzyme encounters a uracil base pair mismatch its 'job' is to remove the wrong base allowing the insertion of the correct matching base, in this case cytosine, by additional enzymes.²² The 'purpose' is to maintain the informational integrity of DNA so that a mutation won't be passed to the next generation during meiosis and mitosis, and metabolism of the organism won't be impaired through faulty transcription. From the perspective of the biochemistry

¹⁸ Chaisson, Eric, 'Practical Applications of Cosmology to Human Society', *Natural Science*, vol. 6, no. 10, 2014, pp. 768, 790.

¹⁹ Pross, *What is Life? How Chemistry Becomes Biology*, p. 4. Referencing Richard Dawkins' *The Blind Watch Maker*, Dawkins notes that animals are the most complicated things in the universe.

²⁰ Gare, Arran, 'Life Questions itself: By Way of an Introduction', *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 4, nos.1-2, 2008, pp. 1-2. Arran Gare contrasts James Lovelock's view that life has purpose against mainstream biologists' view that there is no real purpose in nature. He notes Dawkins view that it is better to characterize life's purposeful nature as teleonomy rather than teleology, since life only has the appearance of purpose.

²¹ (But this driving force is evident in all animate matter, i.e., animate matter purposefully strives to, using a more biocentric descriptor, survive).

²² Cooper, Geoffrey M., Hausman, Robert E., *The Cell. A Molecular Approach*, 7th ed., Sunderland, Massachusetts, 2016, p. 235.

involved, this singular example of metabolism is easily explained. Yet, behind this process one still ponders the ‘why’ question. Why does this repair enzyme go about its business day after day? In other words, what is the driving force behind this example of metabolism and by extension all life? To phrase the question in a non-teleonomic, non-biological way: What facets of the physical universe drive the advancement and maintenance of complexity regardless of the nature of the system?²³

The drive to create and advance the complexity of animate matter will be explained by first defining the forces and mechanisms pushing the creation and advancement of complexity. Secondly, life’s unique characteristics: metabolism, growth, reproduction, and evolution will be explained employing a broad definition of what it means to complexify matter, where, for example, one component of complexification provides a foundation for understanding the tenacity to persist, and other component definitions provide the underpinning for all of life’s unique purposeful characteristics (growth, reproduction, and evolution). It will be shown that the same forces and mechanisms for the creation and advancement of animate complexity equally apply to inanimate matter and the same broad definition of complexification correspondingly explains the advancement of complexity of the inanimate realm. In summary, it will be evident that advancing and maintaining complexity, in and of itself, must be a central component to understanding life’s creation and purposeful nature.

DEFINING COMPLEXITY

A selection of definitions is reviewed referencing the complexity of life at the molecular, systems chemistry, and individual organism level. A specific, followed by a broad, definition of the general complexification of matter is then proposed, offering an explanation for life’s unique features.

Eric Chaisson describes all complex systems as organized, non-equilibrated structures that acquire, store, and express energy. Specific energy flow reifies a complexity metric and is the potential evolutionary driver for all constructive events from the origin of the universe to humans on Earth.²⁴ John Maynard Smith

²³ (Furthermore, this example of complex matter seemingly ‘protecting’ the integrity of other complex matter from our biocentric perspective appears ‘purposeful’. And it is an essential defining trait of animate matter, i.e., animate matter ‘purposefully strives to survive’).

²⁴ Chaisson, Eric J., ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, Cambridge, Cambridge University Press, 2013, pp. 57-59. Eric Chaisson recognizes energy is not the only metric to

acknowledges the difficulty in defining complexity in living organisms but, settles on a qualitative description that recognizes the number of parts composing an organism, or the number of behaviors possible to the organism.²⁵ G.J. Chaitin measures the complexity of a structure by the length of the shortest list of instructions that will generate the structure.²⁶ Addy Prose states complexity is not readily defined, and attempts over the years to quantify the concept within the biological context have not proven too successful.²⁷ He acknowledges the nature of biological complexification as *the* nut that needs to be cracked and in answering the ‘why’ question: “The goal and challenge is to ascertain rules, if such rules exist, that govern processes of complexification.”²⁸ Christian de Duve uses an intuitive meaning, complexity is that which is: the opposite of simple.²⁹

Herein, a definition of complexification of animate and inanimate matter describes advancing molecular complexity as the creation of molecules with increasing numbers of atoms, and increasing systems chemistry complexity by increasing numbers of interactions between molecules and increasing numbers of chemical pathways and their interactions. However, advancing complexity must be understood in its fullest sense to explain the variety, degree, and amount of matter as it complexifies. The following qualifiers define fully inanimate and animate complexification. As with inanimate complexification, the complete list of descriptors of animate complexification will be realized at a level allowed by the physical environment. These descriptors can have variable representation and different hierarchical relationships within any given inanimate or biological system, based on that system’s relation to its environment.

measure complexity of biological systems, though he believes other descriptors such as information content and entropy production are problematic in being narrow, abstract, qualitative, and equivocal. Chaisson, Eric J., *Cosmic Evolution. The Rise of Complexity in Nature*, Cambridge, Massachusetts, Harvard University Press, 2001, p. 13. A general definition applicable to animate and inanimate matter is “. . . a state of intricacy, complication, variety, or involvement, as in the interconnected parts of a structure - a quality of having many interacting, different components”.

²⁵ Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, p. 15.

²⁶ Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, p. 15.

²⁷ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 4-5. Addy Pross draws a distinction in the complexity of say a boulder in terms of its shape, although complex, being arbitrary whereas in the living world complexity is not arbitrary, but highly specific.

²⁸ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 122-124. Addy Pross notes: “The fact that reasonably well defined processes of complexification can be identified suggests that there may be a driving force”. Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, pp. 11-12. Aristotle proposed this concept describing the dual nature of life where material (the egg) is animated by sperm via a formatting force (entelechia). The idea has persisted over the centuries. Leibniz also felt there was entelechia associated with living organisms.

²⁹ de Duve, *Life Evolving. Molecules, Mind, and Meaning*, p. 183.

Advancing complexity includes maximizing the net amount of complex matter; maximizing the variety of complex molecules and systems; maximizing the degree or the level of complexity of molecules and systems; and, importantly, maintaining complexity at a level permitted by the environment where both thermodynamic and kinetic control of reactions occur.

IS THERE TELEONOMY?

This last descriptor of complexification of matter, i.e., maintaining complexity at a level permitted by the environment, when applied to animate matter serves to connect complexification to teleonomy. For at the most fundamental level, the purpose of life is to persist. Yet, for purpose to be fully manifested all the descriptors of complexification will play some part. The tenacity to persist appears as a driving force in both the creation and maintenance of life. This apparent force has been recognized since antiquity, and continues to pervade even the most recent literature.³⁰ Henri Bergson proposed *élan vital* to explain the vigor and drive of animate matter to survive and grow in his book *Creative Evolution* in 1907.³¹ As recently as 2000, Stuart Kaufman recognized the “. . . core of life remains shrouded from view,” stating: “But what makes a cell alive is still not clear to us. The center is still mysterious.”³²

Disregarding the original intention of *élan vital* as a transcendental force, there is, nevertheless, the appearance of a force or a driving mechanism directing the creation and maintenance of life from organic and inorganic precursors.³³ Craig Venter points out: “All cells will die if they cannot make new proteins on a continuous basis to replace those that are damaged or misfolded. In an hour or even less a bacterial cell has to remake all its proteins or perish.”³⁴ Life’s apparent vital force and purposeful nature, which persists within each living cell even as atoms and molecules forming the cell are impermanent, remains a black box for theoretical and evolutionary biologists, and raises the question why this peculiar transition of matter occurs.³⁵ Is this transition

³⁰ Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, pp. 11-12.

³¹ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, p. 33.

³² Pross, *What is Life? How Chemistry Becomes Biology*, p. 114.

³³ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 22-23. (We see it embodied when inorganic and organic matter transform into the complex organic chemistry of living organisms before ultimately returning to the dust of the earth. The cycle of atoms and chemicals transitioning or being transformed through animate matter occurs continuously on a minute-to-minute basis).

³⁴ Venter, *Life at the Speed of Light*, p. 44. (Not only do atoms and chemicals transition through unicellular organisms before returning to the inanimate world but the ultimate fate of all multicellular organisms is to transition to the inanimate realm).

³⁵ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 81, 98-99.

of matter to a higher state of complexity with an apparent teleonomy unique, or is this transition simply a manifestation of the set-forth broad definition of complexification driven forward by the forces and mechanisms proposed and, although different, consistent with the waxing and waning of complexity evident within the universe as a whole?

The purposeful nature of life is self-evident and must be understood when considering the nature of life. Yet, the meaning of “purpose” and whether it exists in reference to animate systems continues to be debated. It is an elusive concept.³⁶ Charles Darwin believed life’s goal is to maximize fitness, which is interpreted as the capacity to survive and reproduce.³⁷ Jacques Monod introduced ‘teleonomy’ in 1971 to indicate an activity directed towards realization of a biological program and that the most important program is the genetic one, i.e. species reproduction and evolution.³⁸ Addy Pross states it is empirically irrefutable that life has purpose, but asks: “What is purpose?”³⁹ He answers, stating the purpose of life is to make more cells. The entire purpose of a cell is directed towards one goal: cell division.⁴⁰ Pier Luigi Luisi referencing the chemical continuity principle emphasizes life transitions through spontaneous and continuous increases in molecular complexity.⁴¹ However, he further proposes that these complex biological systems, in contrast to micelle or crystal formation which are under thermodynamic control, appear to have a rather specific finality, or in other words a purpose and are under kinetic control.⁴² In a similar fashion, Addy Pross notes the law for replicating biological systems is not under thermodynamic control, but replicating biological systems will tend to be transformed from dynamically kinetically less stable to dynamically kinetically more stable systems.⁴³ Pier Luigi Luisi posits that the compounds an organism extracts from the environment are things it lacks for implementing its life, and appropriation of these missing parts is

³⁶ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 32-33. (Certainly the apparent teleonomy of life invites philosophical considerations. Aristotle said life is goal directed. In contrast, by the 16th century a school of thought believed an underlying purpose in nature does not exist).

Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, p. 25. Maynard Smith states unequivocally evolution lacks foresight.

³⁷ Pross, *What is Life? How Chemistry Becomes Biology*, p. 140.

³⁸ Luisi, *The Emergence of Life*, p. 105.

³⁹ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 9, 12.

⁴⁰ Pross, *What is Life? How Chemistry Becomes Biology*, pp. XII, 19.

⁴¹ Luisi, *The Emergence of Life*, p. 39.

⁴² Luisi, *The Emergence of Life*, pp. 105, 109-110. Pier Luigi Luisi notes the critical point in the origin of life scenario is the emergence of kinetic control in chemical reactions and questions if this property emerges spontaneously from a scenario of reactions under thermodynamic control.

⁴³ Pross, *What is Life? How Chemistry Becomes Biology*, p. 77.

what gives meaning and links the autopoietic unit to the world. For him metabolism becomes equivalent to cognition in the simple case of a unicellular organism.⁴⁴ Ed Regis believes the purpose of metabolism is to make something new. For instance, metabolism requires synthesis, rather than merely consumption and destruction of matter.⁴⁵ Nonetheless, the question Addy Pross states remains how purpose could emerge from an objective universe? How can any natural organization of matter act on its own behalf? Addy Pross further asks: “What then is the nature and source of life’s apparent élan vital, that teleonomic character already evident in a bacterial cell?”⁴⁶ Peter Corning proposes the most distinctive property of life is its dynamic goal directedness. Living systems actively pursue survival and reproduction, and they employ an immense variety of different survival strategies in an immense number of different environments. He also notes this internal teleonomy remains something of a “black box” for evolutionary biology, and it is still not understood how this goal directedness in life originated and evolved.⁴⁷ Geoffrey Zubay declares living systems are designed to thrive and replicate in their environment noting several hundred to several thousand reactions proceed simultaneously in the confines of a living cell for the purpose of maintenance and propagation of the system.⁴⁸

The difficulty arriving at a precise definition of life’s purposeful nature is apparent in considering the above-mentioned examples. Yet, all of these imageries of the purpose of life share the commonality that life’s core purpose is the maintenance and propagation of the system.⁴⁹ Organic complexities advanced in the interstellar medium (ISM) and on Earth prior to transitioning to animate matter, although, the specifics for this process in the ISM are only now being explored, and the specifics of advancing

⁴⁴ Luisi, *The Emergence of Life*, pp. 165, 167 171, 105. Pier Luigi Luisi further argues self-replicating micelles and vesicles are not cognitive systems although they are simple autopoietic systems, and therefore autopoiesis is not sufficient but necessary for life. Cognition needs to be added. He also argues the notion of finality (purpose) implies an observer, namely, somebody who gives a valued judgment on the event. (Certainly an observer independent of a system vivifies the systems perceived purpose but in the absence of the observer the system will continue to manifest its existence, growth and evolution. The complexity and logic of metabolism advanced across the animate divide, independent of subjective observation).

⁴⁵ Regis, *What Is Life?*, p. 170.

⁴⁶ Pross, *What is Life? How Chemistry Becomes Biology*, p. 17.

⁴⁷ Corning, Peter A., ‘What is Life? Among other things, it’s a synergistic effect’, *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 4, nos. 1-2, 2008, pp. 235-236. Peter Corning notes that for purpose to become manifest in living systems, synergy between components of living systems, that is, cooperative interactions among various component elements and parts played a central role in catalyzing living systems. (In other words, there must not only be advancing molecular complexity but advancing complexity between the interactions of complex matter).

⁴⁸ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 107

⁴⁹ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 123-124.

organic chemistry in the prebiotic environment of Earth are entirely unknown.^{50,51} However, applying the proposed comprehensive definition of advancing complexity it is clear maintenance and propagation of preanimate systems of increasing complex organic chemistry, and even inorganic chemistry, are indistinguishable from the maintenance and propagation of animate matter.

As organic complexity advanced on the preanimate earth, molecules of advancing complexity competed for substrate, and their survival depended on factors in the local environment. Processes for advancing and maintaining the level of complexity, variety of complexity, and the net volume of complex matter occurred and may have involved any combination of cooperative versus competitive strategies, reactions under thermodynamic or kinetic control, and combination of contingent and deterministic processes.⁵² Regardless whether processes on the preanimate earth were contingent, deterministic, or a combination, the end result was the same - complexity advanced and was maintained, both in degree, variety and net volume.⁵³

If there is purpose to life, and accepting advancing and maintaining complexity is necessary to defining purpose, its definition must be distilled to satisfactorily encompass advancing and maintaining complexity on both sides of the animate divide, i.e., to explain why in the preanimate environment the Neo-Darwinian complexification of organic molecules and rudimentary systems chemistry occurred, and why further complexification of organic molecules and their interactions through advanced systems chemistry occurred in the transition to animate matter. Autopoiesis is defined as the ability of a unit (the cell) to sustain itself through an inner network of reactions that regenerate the system's components. We interpret the autopoiesis of individual organisms as the teleonomy of life. Autopoiesis can be placed under one of the definitions of complexification, that is, the maintenance of a complex system as

⁵⁰ Kwok, Sun, *Physics and Chemistry of the Interstellar Medium*, Sausalito, California, University Science Books, 2007, pp. 254-255.

⁵¹ Schwartz, Alan W., Chang, Sherwood, 'From Big Bang to Primordial Planet', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, Berkeley and Los Angeles, University of California Press, 2002, p. 46.

⁵² Pross, *What is Life? How Chemistry Becomes Biology*, pp. 78-79. The concept of Neo-Darwinian evolution of prebiotic organic molecules has been demonstrated. As just one example, Spiegelman's RNA replication experiment resulted in mutations with mutant strands able to replicate faster.

⁵³ (Though the general realization Neo-Darwinian and Darwinian evolution go hand-in-hand, advancing organic complexity is considered 'purposeful' by many only after transitioning to animate matter. However, from a more encompassing view, this limitation hinges on our constrained subjective anthropocentric prism of arbitrarily defining the advancement and maintenance of organic complexity as purposeful only when applied to the animate side of the divide. This biocentric view is best replaced by a more inclusive definition).

permitted by its environment. When considering life's purposeful nature, the maintenance of complexity is a paramount characteristic. However, a complete inventory of the components of advancing complexity was presented, and to fully invest life's purposeful nature, the full catalogue must be applied to animate matter including advancing the variety and degree of complexity, and maximizing the net amount of complex matter. When applied, these component definitions of complexification explain the full spectrum of life's unique characteristics and purposeful nature.

From the above review a commonality is perceived. At the most fundamental level, the purpose of prebiotic organic chemistry and biotic chemistry is to advance the variety and level of complex matter and maximize and maintain the net volume of complex matter. Advancing and maintaining complexity is clearly a core component to defining the purposeful nature of animate matter, and remains applicable as life transitions from prokaryotic to eukaryotic unicellular organisms and to more advanced multicellular life forms, imbuing a richer sense of purpose as these systems complexify. So the question is: Why does matter complexify?

EXPLORING WHY THERE IS LIFE

Understanding why life is created in the universe is an intriguing question within the realm of life origin's research. The subject is being explored directly or as a subtext to defining what life is, how life was created, and whether life has purpose.⁵⁴ 'Why' questions get at the inherent nature of the system under scrutiny. Defining the forces, mechanisms, and potential laws that bring a system into existence is the most direct approach to understanding why something exists. Forces and mechanisms for the creation of complex systems are balanced by other forces and mechanisms, which can cause their dissolution or destruction. Defining these processes explains why the system exists and explains what must occur for the system to be maintained.

Pier Luigi Luisi believes the transition to life from non-life is a spontaneous and continuous process of increasing molecular complexity, therefore, discrimination between living and non-living is impracticable. He comments that most researchers would not agree with each other as to what is the main motor of upward movement in the ladder of complexity, but he believes there is no transcendental purpose.⁵⁵

⁵⁴ (Can the propensity for the creation of the phenomenon we call life, and the propensity for life to sustain itself and evolve be found within the realm of physics and chemistry? Certainly. The conundrum of why we should be here will be understood through the integration of advancements in the physics, chemistry, organic chemistry, systems chemistry, biology, and philosophical biology of life origins research).

⁵⁵ Luisi, *The Emergence of Life*, pp. 17, 4, 126.

Addy Pross gives considerable attention to why there is life. He asks the question in the sense of identifying the driving force.^{56, 57} He draws distinction between a catalytic reaction, which proceeds linearly, and an autocatalytic reaction that proceeds at an exponential rate. He believes the essence of life is the difference between these two types of reactions, wherein autocatalysis becomes important to life.⁵⁸ The present manuscript proposes that autocatalysis is consistent with one component of advancing complexity - the idea that the net volume of complex matter will continue to increase and maximize. Importantly, Pross differentiates the historical question of how life arose from the ahistorical question of why life arose, making the distinction to identify the driving force behind the process as opposed to defining the exact historical events of life's creation.⁵⁹ He believes that the general answer to the 'why' question will need to be formulated in terms of a general law, independent of the specifics.⁶⁰ He also believes answering the ahistorical question will help to understand the historical question, declaring the ahistorical question of why life is created is the more significant one scientifically; and he also believes it is the less difficult question to resolve.⁶¹ He further notes, “. . . the real challenge is to decipher the ahistorical principle behind the emergence of life, i.e., to understand why matter of any kind would tend to complexify in the biological direction . . . and it is this ahistorical question, independent of time and space, which lies at the heart of the origin of life problem.”⁶² A mechanism is required for the process of complexification far away from equilibrium systems that adhere to the Second Law, notes Addy Pross.^{63, 64}

Stuart Kaufman proposes, “. . . when a sufficiently diverse mix of molecules

⁵⁶ Pross, *What is Life? How Chemistry Becomes Biology*, p. 84.

⁵⁷ Pross, *What is Life? How Chemistry Becomes Biology*, p. 69. Addy Pross begins his query at the molecular level asking why chemical reactions occur. Under thermodynamic control less stable reactants are converted to more stable reactants. But almost any chemical reaction can occur with an appropriate catalyst and energy source.

⁵⁸ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 63-64.

⁵⁹ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 83-85. Addy Pross notes physico-chemical forces induce the process of life's creation, but the picture of how life arose, nevertheless, remains uncertain and highly controversial.

⁶⁰ Pross, *What is Life? How Chemistry Becomes Biology*, p. 85.

⁶¹ Pross, *What is Life? How Chemistry Becomes Biology*, p. 87.

⁶² Pross, *What is Life? How Chemistry Becomes Biology*, p. 100.

⁶³ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 107-108.

⁶⁴ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 122-125. Addy Pross' solution to why complexity advances rest on the power of systems chemistry as the driver of advancing complexity. He notes the challenge becomes defining the rules that govern the process of complexification, if such rules exist, and he believes there may be a driving force for that process, and that systems chemistry can lead to a smooth merging of living and non-living systems.

accumulates somewhere, the chance that an autocatalytic system - a self-maintaining and self-reproducing metabolism - will spring forth becomes a near certainty".⁶⁵

Eric Chaisson has shown as each type of ordered system, from galaxies, stars, planets, and then life, becomes more complex, its normalized energy budget increases.^{66, 67} He believes, “. . . specific energy flow reifies a complexity metric and [is the] potential evolutionary driver for all constructive events from the origin of the universe to humans on Earth.”^{68, 69} He notes, “. . . energy flow as a universal process helps suppress entropy within increasingly ordered, localized systems amidst [an] increasingly disordered surrounding environment”. This process, he suggests, governed the emergence and maturity of our Galaxy, our star, our planet, and ourselves. Therefore, energy itself is a central mechanism of change and a central feature of evolution⁷⁰. A major incite of his work is that energy flow density increases as the complexity of the system increases. He, nevertheless, recognizes system functionality and genetic inheritance help to enhance complexity among animate systems. But he notes, “. . . energy is fuel for change, apparently (and partly) selecting systems able to utilize increased power densities, while driving others to destruction and extinction [are all] in accord with neo-Darwinism’s widely accepted modern synthesis.”^{71, 72} By

⁶⁵ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, p. 50.

⁶⁶ Chaisson, ‘Practical Applications of Cosmology to Human Society’, *Natural Science*, p. 768.

⁶⁷ Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 59. Eric Chaisson states, “. . . energy flow may well be the most unifying process in science, helping to provide a cogent explanation for the onset, existence, and complexification of a whole array of systems - notably, how they emerge, mature, and terminate during individual lifetimes as well as across multiple generations”.

⁶⁸ Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 58.

⁶⁹ Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 59. By normalizing energy flows in complex systems by their mass, the resulting energy rate density can be used to compare different systems. Energy rate density (or power density) is the amount of energy flowing through a system per unit time per unit mass.

⁷⁰ Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 61. Importantly, Eric Chaisson believes this process allows examination of how over the course of time some systems were able to command energy and survive, while others apparently could not and so did not survive.

⁷¹ Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 63.

⁷² Chaisson, ‘Using complexity science to search for unity in the natural sciences’, in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 65. Eric

defining the quantitative relationship between echelons of advancing complexity and energy flow our understanding of why life exists is better understood.

Stanley Salthe specifically addresses the question of why we are here, in addition to where and what are we, and what are we to do⁷³. He employs energy gradient dissipation as a method for describing natural philosophy. Important to his work is the concept of final cause, where finality resides in answers to questions of why something occurs rather than 'where' or 'how'. Recognizing a biological system acts in order to preserve itself and to reproduce, provides a final cause because we have an 'in order to' statement which answers the 'why' question and that answer provides the 'meaning' of a system. Purpose becomes a particular function achieved through work, which he further defines as, ". . . material adjustments or behaviors made in the interests of some system that continues to persist", further noting work in this context ". . . is not a typical 'physical' variable as it associates to finality, [that is], its energy utilization is for a *purpose*".⁷⁴ Commenting on variations of work rate for different biological functions, he notes energy utilization at maximum power will increase as a system grows or develops, concluding development and growth become entrained by the Second Law in light of the maximum entropy production principle.⁷⁵ Form, [i.e., life], is capable of initiating convective flows that move energy from gradients towards the sink more effectively than can haphazard conduction, like diffusion. He concludes the Second Law is the final cause of all form, or that form has teleological meaning.⁷⁶ Thus, the purpose of life and why we are here is to propel entropy production through an advanced complex system of organic chemistry.⁷⁷

Chaisson notes, ". . . optimal ranges of energy rate density grants opportunities for the evolution of complexity; those systems able to adjust, adapt, or otherwise take advantage of such energy flows survive and prosper, while other systems adversely affected by too much or too little energy are non-randomly eliminated".

⁷³ Salthe, Stanley N., Fuhrman, Gary, 'The Cosmic Bellows: The Big Bang and the Second Law', *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 1, no. 2, 2005, p. 2.

⁷⁴ Salthe, Stanley N., 'Maximum Power And maximum Entropy Production: Finalities In Nature', *Cosmos and History: The Journal of Natural and Social Philosophy*, vol.6, no.1, 2010, p. 2.

⁷⁵ Salthe, 'Maximum Power And maximum Entropy Production: Finalities In Nature', *Cosmos and History: The Journal of Natural and Social Philosophy*, p. 3. Stanley Salthe notes this maximum entropy production principle can be manifest as ". . . an energy dissipative system that can assume several to many conformations, [and] will tend to take up one, or frequently return to one, that maximizes the entropy production from the energy gradients it is dissipating - to a degree consistent with that system's survival".

⁷⁶ Salthe, Fuhrman, 'The Cosmic Bellows: The Big Bang and the Second Law', *Cosmos and History: The Journal of Natural and Social Philosophy*, vol. 1, no. 2, 2005, p. 5.

⁷⁷ Luisi, *The Emergence of Life*, p. 87. (A classic example in support of Stanley Salthe's theory is the thermodynamically favored construction of micelles, reverse micelles, and vesicles where an ordered structure is the direct byproduct of the overall increase in entropy. However, thermodynamically

Understanding why there is life is approached from many avenues, as evident from these examples. Why there should be life is considered employing a tiered energy flow metric to explain the existence of increasingly complex inanimate and animate matter; a teleonomic description where animate matter exists to enhance entropy production; or a description relying on inherent qualities of the system, i.e., the manifestation of autocatalysis, catalytic closure, systems chemistry, and autopoiesis which provide a sufficient description of why life exists. All of these views on why there is life are profoundly helpful in gaining a broad understanding to the question. Ideally, there should be no further requirement ascribed to why a system exists other than its necessary creation, perpetuation and destruction by physical laws and mechanisms. This manuscript considers why we are here from the viewpoint of what actually drives complexification and secondly considers whether the processes and results of complexification are intrinsically different on either side of the animate-inanimate divide.

WHAT IS LIFE?

A clear, unambiguous definition of life would help as we try to understand why life should occur. A consensus has not been achieved, in large measure because of life's multifaceted nature. Although having an innate understanding of life, we have difficulty defining its essential characteristics.

Eric Chaisson defines life as “. . . an open coherent, space-time structure kept far from thermodynamic equilibrium by a flow of energy through it - a carbon based system operating in a water medium with higher forms metabolizing oxygen”.⁷⁸ Ed Regis in his book *What is Life* references other scientists' views on this subject. Researchers whose goal is to create life have stripped down their designs for creating a minimal living entity. One definition of a minimal living entity used by Steen Rasmussen has three components: 1) the ability to take in nutrients and turn them into energy, 2) the ability to reproduce, and 3) the ability of descendants to evolve by means of natural selection.⁷⁹ For Erwin Schrödinger something is alive when it is “. . . doing something, moving, exchanging material with its environment, and so forth, and that

unfavorable reactions advancing complexity through mechanisms, such as dynamic kinetic control, also must adhere to the Second Law). Chaisson, *Cosmic Evolution. The Rise of Complexity in Nature*, p. 146. Eric Chaisson states, “. . . for all structured systems, entropy increases of the larger surrounding environment can be mathematically shown to exceed the entropy decreases of the localized systems . . .”

⁷⁸ Chaisson, 'Using complexity science to search for unity in the natural sciences', in Charles H. Lineweaver (ed.), Paul C.W. Davies (ed.), Michael Ruse (ed.), *Complexity and the Arrow of Time*, p. 63.

⁷⁹ Regis, *What Is Life?*, p. 15.

for a much longer period than we would expect an inanimate piece of matter to ‘keep going’ under similar circumstances.”⁸⁰ Manfred Eigen lists three essential characteristics: 1) self-reproduction, 2) mutation, and 3) metabolism.⁸¹ However, Stuart Kaufman questions if self-replicating molecular structures and a genetic code are essential to life suggesting certain kinds of stable collective dynamics may be both necessary and sufficient for life.⁸² He believes life is an emergent phenomenon; a by-product of molecular interactions that as the system increases in complexity and diversity, life emerges.⁸³ John Maynard Smith in his book *The Origins of Life* references other scientists’ views. Freeman Dyson recognizes life’s duality of metabolism and genetic control, but believes the emphasis should be on the metabolic component to understand life’s origins.⁸⁴ In a similar fashion, Tibor Ganti defines the essential characteristic for life as ‘absolute’ and ‘potential’. The ability to reproduce is a potential but not absolute criterion, whereas, metabolism and informational control are absolute.⁸⁵ Geoffrey Zubay questions if cellular structure, nucleic acids, and proteins are essential for life. However, he states the focus must be on functions more than chemical characteristics to arrive at a broader definition. The two functions essential for life are the ability to replicate and the capacity to undergo change.⁸⁶ Pier Luigi Luisi’s essential characteristics for life are self-maintenance, reproduction, and evolvability of the system.⁸⁷ Humberto Maturana and Francisco Varela describe a living system as composed of a semipermeable membrane, which is produced within the system that encompasses reactions that regenerate the compounds.⁸⁸ John Oro defines a living system as a “. . . self-maintained organic structure operating in an aqueous medium as a self-regulated negentropic process that exchanges matter and energy with the environment and is capable of self-reproduction, evolution by natural

⁸⁰ Regis, *What Is Life?*, p. 34.

⁸¹ Regis, *What Is Life?*, p. 65.

⁸² Regis, *What Is Life?*, p. 67.

⁸³ Regis, *What Is Life?*, p. 69.

⁸⁴ Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, p. 12.

Regis, *What Is Life?*, p. 72. For Freeman Dyson life is metabolism, which he considers more important than replication, development, and growth.

⁸⁵ Smith, Szathmary, *The Origins of Life, From the Birth of Life to the Origins of Language*, p. 13.

⁸⁶ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 168, 170-171. Geoffrey Zubay extrapolates back to more fundamental life forms questioning whether proteins were necessary and even whether the cell membrane was essential, which leads him to consider the earliest life was RNA based.

⁸⁷ Luisi, *The Emergence of Life*, p. 245.

⁸⁸ Luisi, *The Emergence of Life*, p. 158.

Luisi, *The Emergence of Life*, p. 161. Francisco Varela recognized “. . . a living system can also exist without being capable of self-reproduction”.

selection, and adaptation to the environment.”⁸⁹ Clifford Grobstein states: “Life is macromolecular, hierarchically organized, and characterized by replication, metabolic turnover, and exquisite regulation of a spreading center of order in a less ordered universe.”⁹⁰ James Ferris defines life by increasing levels of complexity.⁹¹

Whether metabolism or replication came first, evolved separately, or were co-dependent remains an active subject of debate. Stuart Kaufman argues for metabolism first, while Freeman Dyson proposes both occurred independently.⁹² However, this dilemma becomes moot under the proposed broad definition of complexification where maintenance of a complex system (metabolism) is on equal par with both an increase in the net volume of the material of a system (growth and reproduction), and maximization of the level and variety of the components of a complex system (evolution).

The attempts to define life seen above, focus primarily on functional attributes of living organisms and one physical characteristic, the plasma membrane, which creates an internal environment. In tallying the properties in order of considered importance first is metabolism and a cellular environment of which there is unanimity of opinion, followed by reproduction and evolvability.

Metabolism, although an essential component in defining complexity of animate matter, can remain dormant for extended intervals as in the slow metabolism of endoliths⁹³, life transitioning through a non-metabolizing seed or spore stage,

⁸⁹ Oro, ‘Historical Understanding of Life’s Beginnings’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 8.

⁹⁰ Oro, ‘Historical Understanding of Life’s Beginnings’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 9. (This spreading center of order is manifest outside the plasma membrane by the cell wall of bacteria and by the extracellular matrix, intravascular volume, third and forth space compartments, ligaments, tendons, osseous structures, and organs of multicellular life where complexity has been transposed outside the cellular environment).

⁹¹ Ferris, James P., ‘From Building Blocks to the Polymers of Life’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, Berkeley and Los Angeles, University of California Press, 2002, pp. 113-114. Version 1 is the minimalist definition. Life is a self-sufficient system maintained by replication and subject to change by mutation. This is an RNA world where nucleic acids are sustained by an external source of nutrients with the complex bound to a mineral surface. Version 2 adds a semipermeable membrane barrier to maintain the integrity of the system. Version 3 adds the protein molecular machinery to metabolize ingested nutrients.

⁹² Pross, *What is Life? How Chemistry Becomes Biology*, pp. 100-104. (Replication first scenarios require a viable explanation of how (and why) a simple replicating system would be induced to complexify and climb up a thermodynamic gradient. If metabolism occurred first, the same questions are raised of how (and why) metabolic cycles would form spontaneously and how (and why) they would be induced to maintain themselves).

⁹³ Schultz, Steven, ‘Two miles underground’, *The Princeton Weekly Bulletin, Office of Communications*, 2016.

extracellular viruses, and tardigrades.⁹⁴ However, the potential must remain intact. Maintaining the level of complexity allowed in an environment is one component of the broad definition of complexification. Maintaining the level of animate complexity is synonymous with metabolism.

Reproduction and growth are intertwined. Reproduction subsumes there has been growth; otherwise the cytoplasmic volume of animate matter would continue to decline with each cellular division.⁹⁵ Also there is an upper limit to cytoplasmic volume beyond which the metabolic machinery becomes inefficient, and metabolism would likely falter and fail in unicellular life and most multicellular life.⁹⁶ Therefore, as the net volume of animate matter increases cell division must occur. Growth, which results in an increase in the net volume of animate matter, eventually requires cellular division, and although highly characteristic of life, growth and cell division are not essential for individual cells. Still, growth and reproduction are inherently indispensable for multicellular life, and when considering unicellular and multicellular life at the population level. Growth and reproduction are expressions of maximizing the net volume of animate matter.

Evolvability is an attribute of unicellular and multicellular life characteristically occurring at the species level during reproduction when errors in DNA or RNA duplication can occur.⁹⁷ Maximizing the degree and variety of complexity are two components of the general complexification of matter, so for animate complexity to be fully realized evolution will occur. Evolution is a manifestation of increasing the level and variety of complexity of animate matter permitted in an environment.

In summary, the essential components of life for individual organisms are two, one physical and one functional: a cellular structure that metabolizes or in non-biological terms, complex matter that is self-contained and persists within its environment. However, for all components of advancing complexity defined above to be fully realized - maximizing the volume, variety, and level of complex matter - requires, at the population or species level, not only metabolism, but also growth, reproduction,

⁹⁴ Lane, *The Vital Question. Energy, Evolution, and the Origins of Complex Life*, p. 55.

⁹⁵ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, p. 42. There is a minimum cytosolic volume, below which it appears life cannot exist. Pleuronoma, the smallest free-living organism contains only a few hundred genes.

⁹⁶ Lane, *The Vital Question. Energy, Evolution, and the Origins of Complex Life*, p. 99. Nick Lane states, “. . . the problem of surface-to-volume ratio must set a limit to the size of cells”, which is a “. . . matter of supply of reactants and removal of waste” where if “. . . these waste products are not physically removed from the cell, they prevent the forward reactions from continuing”.

⁹⁷ Cooper, Hausman, *The Cell. A Molecular Approach*, pp. 113, 669-670. (Single cell organisms can evolve absent cell division through the exchange of plasmids, for example. Contrariwise, at the species level, unicellular or multicellular life may persist, grow and reproduce without evolving, where individuals perish yet the species remains unchanged for indeterminate times).

and evolution to be manifest. Pertinent to all matter, the descriptors of advancing complexity and level of expression or at times absence of expression of the individual components of complexification will reflect what the environment permits depending on thermodynamic stability, dynamic kinetic stability, and energy and metabolite fluxes of animate matter. Although the underlying basis of life's diversity continues to trouble biologists, considering the complexification of animate matter employing the broad definition proposed facilitates our understanding of life's assorted and unique attributes.⁹⁸

A DIFFERENT PERSPECTIVE ON LIFE

The difficulty characterizing life partly results from inability to subdue our biocentric prejudices. Perhaps disengaging from our anthropocentric worldview, further insight will be achieved into what life is and how animate matter relates to the universe as a whole. This paper approaches the question of why life is created from this a-biocentric perspective. Addy Pross states: "Simply put, within the material world there exists an entire class of material systems - the biological class - that exhibits a distinct pattern of behavior that remains unexplained in chemical terms . . . Somehow we know more and more of the cell's mechanisms, yet that molecular knowledge seems to bring us no closer to understanding the essence of biological reality . . . Understanding life will require that we are able to offer unambiguous explanations for life's unique characteristics."⁹⁹ Utilizing a broad definition of complexity, commonalities of increasing complexity between the animate and inanimate realm are explored. Examining traits recognized as unique to animate matter and reconsidering those traits in a way consistent with similar attributes of advancing complexity in the inanimate universe, coherence is sought between the evolution of increasing complexity of the inanimate realm and the creation and evolution of life.

Reviewing what is understood of the general evolution of the universe, similarities of complexification between inanimate and animate matter are considered with a common metric. The goal is to understand the forces, mechanisms, and laws of nature that propel advancing complexity and demonstrate those same effectors explain advancing complexity of the inanimate and animate world. The qualities considered unique to life, i.e., creation, metabolism, growth, reproduction, evolution, and the more hierarchical descriptors of 'self', purpose, and the driving force behind self-preservation are explored using this more general framework and by employing a comprehensive definition of the complexification of matter.

⁹⁸ Pross, *What is Life? How Chemistry Becomes Biology*, p. 24.

⁹⁹ Pross, *What is Life? How Chemistry Becomes Biology*, pp. 30-31.

OBSERVATIONS ON THE CREATION AND EVOLUTION OF THE INANIMATE UNIVERSE

Creating elements

From the beginning of the universe the amount, variety and complexity of matter, elemental and molecular, has been increasing within local environments. When elements and subatomic particles interact the variety and complexity of elemental matter advances. Gravity drives this process by increasing the concentration (proximity) and energy of elemental matter.^{100, 101, 102} Within seconds of the big bang, gravity began to compete with the expansion of the original explosion. Due to the inhomogeneity of matter in the early universe, gravity resulted in coalescence of clouds of hydrogen and helium into stars, where gravitational energy was converted into heat creating the tremendous collision velocities necessary to overcome repulsion between positive charged nuclei.¹⁰³ The creation of atoms of increasing atomic number occurred in the core of stars where gravitational collapse of the primordial molecular cloud resulted in dramatic increases in kinetic energy and concentration of elemental particles.¹⁰⁴ Gravity drives this process by maintaining high concentrations of matter

¹⁰⁰ Kutter, Siegfried G., *The Universe and Life, Origins and Evolution*, Boston/Portola Valley, Jones and Bartlett Publishers, Inc., 1987, p. 131.

¹⁰¹ Cohen, Martin, 'Star Birth and Maturity', in Byron Preiss (ed.), Andrew Fraknoi (scientific ed.), *The Universe*, Toronto, New York, Bantam Books, 1987, p. 69.

¹⁰² Abell, George O., Morrison, David, Wolff, Sidney C., *Exploration of the Universe*, 5th ed., Philadelphia, New York, Chicago, San Francisco, Sanders College Publishing, 1987, p. 520.

Newton, David E., *Chemistry of Space*, New York, Facts On File, An Imprint of Infobase Publishing, 2007, p. 6. Within 10 seconds after the creation of the universe all the fundamental particles, which make up matter, had been formed. Newton, *Chemistry of Space*, pp. 7-8. Much of this matter was destroyed by matter-antimatter interaction leaving a small excess of matter.

¹⁰³ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 23-24. (Absent this inhomogeneity of the early universe, gravity may have not resulted in a coalescence of matter and subsequent star formation).

¹⁰⁴ Schwartz, 'From Big Bang to Primordial Planet', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, p. 48. The heavy elements, i.e., elements with an atomic number greater than four, are forged through nuclear fusion reactions within stars. Atoms of atomic weight less than iron are formed in this manner. These reactions release energy, which explains why stars shine. Chaisson, *Cosmic Evolution. The Rise of Complexity in Nature*, pp. 161-162. Eric Chaisson states: "Those massive stars . . . needed to produce heavy elements . . . [resulted in] gradually enriching the ISM with greater elemental complexity; such rising complexity further promotes planetary systems that act as abodes for life", noting, ". . . planets generally become comparable to or a bit more complex than stars", where one such planet ". . . ripened for the emergence of the even more highly ordered system of life itself. Briefly, the bulk of a planet's order derives from the energy gained via gravitational accretion of raw proto-planetary, initially homogeneous matter, whereupon the onset of energy flow created its geological complexity, from core to surface". Chaisson, *Cosmic Evolution. The Rise of Complexity in Nature*, p. 73. Eric Chaisson states: "The order [of a star

and from conversion of gravitational energy into heat for nuclear fusion to continue.¹⁰⁵ Creation of elements with an atomic number greater than 26 is largely through the process of neutron capture.¹⁰⁶ Beyond the element polonium ($Z=83$) the rapid (R) process neutron capture is required. In a supernova explosion the initial implosion of the star through gravitational collapse occurs. Extreme pressure at the core forces electrons into protons creating neutrons and destroying iron nuclei. The enormous increase in neutrons created from this destructive process increases the density of matter outside the core allowing heavier elements beyond polonium, but with short half-lives, to undergo the S neutron capture process, consequent to high concentration of neutrons which can rapidly interact with these heavier but unstable elements.¹⁰⁷ The shock wave following the initial implosion generates extreme pressures and temperatures in the outer layers, resulting in an enormous rise in fusion processes creating elements of atomic weights greater than iron.¹⁰⁸ The shock wave of a supernova explosion acts as a surrogate to gravity greatly increasing pressures and densities of matter, further driving elemental evolution.¹⁰⁹ Of the four forces of nature gravity drives the creation of elements within stars by maximizing proximity and kinetic energy of matter.

Molecular Creation

While the creation of the elements depends on gravity and its surrogate mechanism

or planet] is generated by the long-range, attractive gravitational force; the disorder is generated in the conversion of gravitational energy to heat energy”, which is ejected into its surrounding.

¹⁰⁵ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 23-24.

¹⁰⁶ Newton, *Chemistry of Space*, pp. 70-74. (Slow (S) neutron capture is common in massive stars because of the abundance of neutrons created from the burning of carbon, and neon for example. But these processes occur slowly over hundreds to thousands of years and require fairly stable isotopes for the neutron capture to occur).

¹⁰⁷ Newton, *Chemistry of Space*, pp. 75-77.

¹⁰⁸ Newton, *Chemistry of Space*, p. 77.

¹⁰⁹ Schwartz, ‘From Big Bang to Primordial Planet’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 48. Kutter, *The Universe and Life, Origins and Evolution*, pp. 157-158. The collapse of the stellar core proceeds so quickly, the envelope is left behind. The collapse releases a tremendous amount of energy. Some of this energy goes into creating a shock wave heating matter in the envelope resulting a brief period of nuclear synthesis in the silicon and oxygen layers cascading to form heavier elements such as copper, zinc, silver, and gold. The energy required for fusion reactions is supplied by the shock wave. Marshall, Laurence A., *The Super-Nova Story*, Plenum Press, New York and London, 1988, p. 205. Laurence Marshall notes, elements heavier than iron, particularly those with a large number of neutrons, result when nuclei are subjected to an intense burst of neutrons, stating: “The outgoing shock wave in a Type II supernova should generate just such a flood of neutrons as it hits atoms in its path. Bombarded by the neutrons, nuclei in the overlying gas rapidly grow fatter and fatter, and within seconds all the nuclei up to uranium can be formed”.

within stars, the electromagnetic force is compulsory for chemical reactions and acts as the fundamental energy source.¹¹⁰ However, since reactions cannot occur without contact between atoms or molecules, mechanisms enhancing proximity are critical to the chemistry of molecular constructions, just as in the construction of elements within stars. Gravity is the prime mechanism for bringing reactants into apposition. Nonetheless, there are other surrogates of gravity, which can also enhance proximity of reactants.

The Interstellar Medium (ISM)

The past forty years have witnessed a rapid progression in our understanding of the rich organic chemistry occurring in the interstellar medium (ISM).¹¹¹ The composition, molecular abundances¹¹², and physical characteristics of the ISM such as temperature, density, and the intensity and type of electromagnetic and cosmic radiation of interstellar, circumstellar, and protostellar clouds have provided additional insight into the constraints and possibilities for the creation or destruction of advanced organic chemistry.¹¹³

The reason for the rich organic chemistry of the ISM is carbon's (C) capacity to form a variety of bonds with itself and other elements and for these bonds to be relatively easily broken. This allows for the progression of increasingly complex molecular constructions.¹¹⁴ ¹¹⁵ The first stars produced large amounts of carbon and

¹¹⁰ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 21.

¹¹¹ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. XI. Knowledge has advanced because of the technical revolution in telescope design that has opened the electromagnetic spectrum beyond visible light to spectroscopic analysis. Earth based and space based telescopes gathering electromagnetic waves across the spectrum permit spectroscopic identification of atoms, molecules, and grains of increasing complexity. For example, infrared and millimeter spectroscopy from space has allowed the identification of scores of molecules through their stretching and bending vibrational, and rotational modes.

¹¹² Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 279, 293.

¹¹³ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. XI, XII, 3. Prior to these advancements it was generally believed complex chemistry whether organic or inorganic was likely limited due to extremes of temperature and density of matter of the ISM and the harsh conditions of the ISM where cosmic radiation and radiation in the UV range and beyond would be destructive to advanced chemical constructions. These concerns have given way to the realization that within varied environments of the ISM an advanced organic chemistry is creating aliphatic and aromatic compounds, PAH's, and other complex molecules including sugars, amino acids and other building blocks of animate matter.

¹¹⁴ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 196, 343.

¹¹⁵ Oro, 'Historical Understanding of Life's Beginnings', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, p. 11. Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 353. Carbon's chemical versatility results in reactions that easily polymerize or form chains or rings. As a result, compounds of carbon vastly outstrip in abundance and complexity the inorganic chemistry of silicates and other elements of the ISM.

oxygen (O).¹¹⁶ The ISM, composed primarily of hydrogen (H) and helium (He), was enriched by the solar wind of these early generation stars, delivering to the ISM these and other metals, simpler carbon based molecules, and grains, which are composed, in part, of macromolecular carbon.¹¹⁷

The ISM is varied in composition and physical attributes. The ISM is categorized into interstellar clouds ranging from dense to diffuse, protostellar clouds, and circumstellar envelopes. Interstellar clouds are composed mostly of hydrogen and helium molecules in the gas (molecular) phase. Approximately one percent of matter is composed of grains.¹¹⁸ Interstellar clouds' proximity to local stars influences the type and degree of chemistry that can occur.¹¹⁹

There are two types of interstellar clouds. In Cold Dark Clouds temperatures are around 10K. They have a high density of 10^6 atoms per cm^3 , which attenuates UV radiation and offers a protected environment to form larger molecules by gas-phase and ice chemistry on grains.¹²⁰ More than 150 complex organic gas-phase molecules have been observed.¹²¹

Diffuse Interstellar Clouds have a low density of 10^3 atoms per cm^3 and temperatures of less than 100K. Heating the diffuse ISM comes from photoionization by diluted starlight and collisional ionization by cosmic rays.¹²² Interstellar molecules are readily destroyed by photodissociation but destruction is balanced by a number of formative processes.¹²³ Gas density under all interstellar conditions is so low that multiparticle gas-phase reactions are unlikely. Therefore, bi-particle reactions are the major processes forming molecules in the gas phase.¹²⁴ In lieu of the low density of the ISM a number of mechanisms can bring reactants into proximity, so that reactions can

¹¹⁶ Ehrenfreund, Pascale, Spaans, Marco, Holm, Nils G., 'The evolution of organic matter in space', *Philosophical Transactions of the Royal Society A*, vol. 369, 2011, p. 539.

¹¹⁷ Ehrenfreund, 'The evolution of organic matter in space', p. 539.

Ehrenfreund, 'The evolution of organic matter in space', p. 540. It is believed active carbon chemistry has been ongoing for at least 10Gy.

¹¹⁸ Ehrenfreund, 'The evolution of organic matter in space', p. 541.

¹¹⁹ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 3-5.

Ehrenfreund, 'The evolution of organic matter in space', p. 542. For example, circumstellar envelopes are factories for complex molecular synthesis.

¹²⁰ Ehrenfreund, 'The evolution of organic matter in space', p. 541.

Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 407. Cosmic rays lose only a small fraction of their energy in one ionization allowing cosmic rays to reach deep into dense regions and so are important in initiating chemistry in dense clouds shielded from interstellar radiation.

¹²¹ Ehrenfreund, 'The evolution of organic matter in space', p. 541.

¹²² Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 184.

¹²³ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 407-408.

¹²⁴ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 408.

occur between species. These include ion-neutral collisions, neutral-neutral collisions, ion-molecular reactions, neutral-neutral reactions, radiative recombination, and dissociative recombination. Kinetic factors, electrostatic attraction with ionic species and neutral species through Van der Waal forces supplement gravity in bringing reactants together for chemistry to proceed.^{125, 126}

Photon-dominated regions (PDR) of the ISM have large UV fields from a hot central star. Molecules are broken down on time scales of less than a year. Yet intense molecular-line emissions are observed. Obviously molecules are quickly and abundantly reformed. Accordingly, in a high density, high temperature region in a UV radiation field, in spite of higher photodissociation rates, higher molecular abundances are possible. Gas temperatures in the order of 1000K enable endothermic reactions and rapid processing of molecules.¹²⁷

Grain surface chemistry

Dust in other galaxies, even those with large redshifts suggests grain formation occurs early in the history of galactic evolution.¹²⁸ Evidence indicates silicate (Si) and silicate-carbon (SiC) grains condense in the upper stellar atmospheres of oxygen and carbon rich stars and are then ejected by radiation pressure.¹²⁹ Sun Kwok believes in carbon rich stars condensation of carbonaceous material probably begins with growth of C on SiC seeds. He notes when gas is cooled to 1100K aromatic molecules formed in the gas phase will condense onto the surface of grains.¹³⁰ In circumstellar envelopes of carbon rich stars, where density will be greater than the ISM, organic molecular species of a wide variety of complexity have been discovered.¹³¹ Sun Kwok states chemical processes in this environment are extremely efficient in transforming simple molecules into complex molecules.¹³² Diffusion of heavier species over grain surfaces

¹²⁵ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 407-413.

¹²⁶ Ehrenfreund, 'The evolution of organic matter in space', p. 542.

¹²⁷ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 415. Ordinary interstellar clouds are entirely molecular and rich in molecular species at T 10-20K but it takes millions of years to reach such a full and rich molecular state at such temperatures, even under heavy protection by dust.

¹²⁸ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 305. Kwok, Sun, *Organic Matter in the Universe*, Singapore, Wiley-VCH, 2012, p. 95. Molecular species and solid-state compounds thought to be carbon were synthesized very early in the formation of the universe in the ISM and their wide presence suggest the chemical processes were extremely efficient.

¹²⁹ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 377.

¹³⁰ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 378.

¹³¹ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 378.

¹³² Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 378.

can become significant at higher temperatures. Near a protostar heavy atoms become mobile on the surface enabling surface encounters between atoms so that heavy molecules form in abundance.¹³³

As mentioned, gas-phase chemistry is unable to account for the abundance of all molecular species, and many of the complex organic molecules are difficult to synthesize in the gaseous phase. It is likely chemical processes on the surface of grains play an important role in interstellar chemistry, notes Sun Kwok.¹³⁴ He states, the site of organic synthesis is believed to be on grain surfaces and with an external energy source chemical reactions can take place on the ice mantle of grains. A rich variety of moderately complex organic molecules can be produced.¹³⁵ Pascale Ehrenfreund believes chemical pathways that could not proceed in the gas phase were possible with surface catalysts on solid interstellar particles leading to the formation of complex molecules¹³⁶ and that surface catalysis on solid interstellar particles enables molecular formation and chemical pathways that cannot proceed in the gas phase due to reaction barriers.¹³⁷

Once solid-state material is formed in the circumstellar environment it is suspected further processing occurs by interstellar UV radiation, cosmic rays and shocks, with further processing occurring in the cold, dense gas in molecular clouds.¹³⁸ In the ISM, UV processing of ice mixtures suggests the chemical composition of interstellar grains can be altered creating a rich variety of moderately complex organic molecules.¹³⁹

¹³³ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 422-423. Sun Kwok notes: "It has also been suggested compounds of high molecular weight can be produced on grains through polymerization reactions . . . The richness of the chemical compositions can be further enhanced if these ices are subjected to irradiation by interstellar diffuse UV light".

¹³⁴ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 418.

¹³⁵ Kwok, *Organic Matter in the Universe*, p. 166.

Kwok, *Organic Matter in the Universe*, pp. 166-168. Experiments mimicking the low density ISM environment with solid grain chemistry exposed to UV light suggest spontaneous generation of AA's is possible in the ISM.

¹³⁶ Ehrenfreund, 'The evolution of organic matter in space', p. 541.

¹³⁷ Ehrenfreund, 'The evolution of organic matter in space', p. 541. Pascale Ehrenfreund notes that more complex molecules can form in the gas phase in cold dense clouds than in diffuse clouds do to freeze out of most species (except H₂ and He), and attenuation of UV radiation from the high density.

¹³⁸ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 377. Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 324. Grains can grow or be destroyed for a variety of reasons. Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 312. Grains can be heated by diffuse starlight or by a central star. Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 323. Grains are subject to further processing through growth, erosion, sputtering, and coagulation.

¹³⁹ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 385. Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 386, 395. Experimentally, under artificial conditions of the ISM, UV photolysis of amorphous

“When exposed to the diffuse interstellar UV radiation field, molecules are usually destroyed in less than 300 years. Molecules are, in turn, constantly formed from atoms and atomic ions”, notes Sun Kwok,¹⁴⁰ stating that, with the help of dust shielding and self-shielding against diffuse interstellar UV radiation molecular abundances rise.¹⁴¹

Spectroscopic evidence of diffuse interstellar bands (DIB) is considered to represent complex organic molecules.¹⁴² Also, the existence of spectroscopic plateau emission features is thought to represent carbonaceous grains and suggests the structure of carbonaceous grains is complex and probably includes a variety of alkane and alkene side groups attached to aromatic rings¹⁴³, and may have a structure similar to coal.¹⁴⁴

Gravity enhances the proximity of elements and molecules, particularly in circumstellar environments and dense clouds of the ISM. Other mechanisms bringing matter into apposition include shock waves, the solar wind, electrostatic forces between molecules and atoms, collisions, and grain surface chemistry. When proximity of matter is increased, as in the condensation of molecules onto grains, endergonic or exergonic reactions can occur and will increase organic molecular complexity with compounds of dozens or even hundreds of atoms.¹⁴⁵ When dust aggregates further, such as in solar nebulae, some of this solid matter becomes incorporated into comets and asteroids. Analysis of carbonaceous meteorites provides strong evidence interstellar organic matter is varied, complex and preserved intact in meteorites through the formation of the solar system.¹⁴⁶

The specific interstellar environment is important in determining the degree and variety of organic complexity and quantity of organic material created. Different environments result in creation but can also result in destruction of advanced chemical constructions. Turnover of the highest level of complex compounds allowed by the environment will occur when molecules are created through endergonic pathways. When the proximity or concentration of matter is enhanced by gravity, as occurs in

water ice mixed with CH³OH, HCN, and NH³ occurs, and with further processing, the spontaneous generation of amino acids, nucleic acid bases in the ISM is possible.

¹⁴⁰ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 397-398.

¹⁴¹ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 398. Ehrenfreund, “The evolution of organic matter in space, p. 542. Pascale Ehrenfreund states: “In diffuse interstellar clouds dust interacts with hot gas, UV radiation and cosmic rays and evolves or gets destroyed by shock waves and by sputtering”.

¹⁴² Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 367-368.

¹⁴³ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 375.

¹⁴⁴ Kwok, *Organic Matter in the Universe*, p. 106.

¹⁴⁵ Kwok, *Physics and Chemistry of the Interstellar Medium*, p. 396. Although it remains unknown how these reactions occur and how complex is the solid organic matter within the ISM, the evidence indicates complexity of interstellar dust is likely advanced.

¹⁴⁶ Kwok, *Physics and Chemistry of the Interstellar Medium*, pp. 392-393.

circumstellar envelopes, dense clouds, and grain surfaces, and through electrostatic and kinetic factors, it appears the greatest variety and level of complexity will be achieved. Against this backdrop of why advancing complexity occurs within the ISM, what similarities are there of increasing complexities of organic molecular species on the prebiotic earth?

Earth's preanimate organic evolution

Carbon compounds from the original solar nebula were likely destroyed during Earth's formation. Later the earth was enriched with organic building blocks through collisions with extraterrestrial objects.¹⁴⁷ Alan Schwartz states the theoretical assessment of extraterrestrial sources of organics that may have played a role in life's origins points to interstellar dust particles as the likely predominant carriers of simpler organic compounds.¹⁴⁸ It is believed chemical processes on Earth resulted in new constructions of building blocks of animate matter – amino acids, nucleic acids, sugars, and lipids with a number of these pathways reacting on catalytic surfaces.¹⁴⁹

For complexity of matter to advance beyond that achieved in the ISM an environment was required where proximity of organic molecules and other reactants was enhanced compared to circumstellar regions, the dense ISM, and grain surfaces but absent the destructive effects of the near solar and interstellar environments. The earth provided this environment by greatly enhancing proximity of reactants primarily through gravity's influence on solid, liquid, and gaseous matter at the earth's surface. However, proximity was further augmented through surrogates of gravity, which potentially included evaporation, freezing, and concentrating reactants on clay surfaces and alkaline vents.

Clay surfaces enhance proximity by bringing reactants into juxtaposition; they can catalyze reactions, stabilize intermediates, and then catalyze subsequent reactions.¹⁵⁰ James Ferris notes minerals on the primitive earth provided a “library” of surfaces for

¹⁴⁷ Ehrenfreund, 'The evolution of organic matter in space', p. 544. It is believed much of this material arrived during the period of Late Heavy Bombardment. How much of that material survived in the form of the building blocks of animate matter is unknown.

¹⁴⁸ Schwartz, 'From Big Bang to Primordial Planet', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, p. 71.

¹⁴⁹ Ehrenfreund, 'The evolution of organic matter in space', p. 544.

¹⁵⁰ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 391. Ferris, 'From Building Blocks to the Polymers of Life', in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, pp. 121-124. J. D. Bernal in 1949 was the first to propose prebiotic reactions of organic compounds could proceed by concentrating reactants through selective adsorption on clay surfaces.

the exploration of molecular evolution.¹⁵¹ While clay surfaces, evaporation, and freezing were potentially important in concentrating reactants over and above the effects of gravity, the electromagnetic force, essential for chemistry, also provided ample energy from the sun for driving reactions.¹⁵² The result was matter of a broad population of elements and simpler molecules were concentrated and could interact.

The importance of concentrating organic matter to advance chemical evolution is broadly recognized.¹⁵³ Geoffrey Zubay declares, “. . . mechanisms for concentrating reactants and products would be very useful and probably essential in some cases. This is particularly true for bimolecular and multimolecular reactions.”¹⁵⁴ Through mechanisms of concentrating reactants organic abiotic reactions will form amino acids¹⁵⁵, the purines: adenine and guanine, and the pyrimidines: cytosine and uracil. ¹⁵⁶ The prebiotic synthesis of sugars is a multistep process requiring a catalyst, which can be a clay mineral.¹⁵⁷ It is likely that the proximity of reactants on a clay surface facilitates the reaction sequence. Nucleosides are formed by condensation of a sugar and a purine by allowing them to evaporate to dryness, which concentrates the reactants and makes nucleoside formation thermodynamically favorable by removing water.¹⁵⁸ It is believed, states Robert Hazen: “The seas of ancient Earth became increasingly concentrated in the stuff of life, as biomolecules rained from the skies and rose from the depths.”¹⁵⁹

¹⁵¹ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 393.

¹⁵² Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 174-175.

Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 183. Because the earth was bathed in excess radiation from the Sun, notes Geoffrey Zubay, the solar energy was more than adequate to overcome the negative entropy problem, therefore chemical reactions were not limited by energy, thus only kinetic factors were decisive in chemical evolution.

¹⁵³ Oro, ‘Historical Understanding of Life’s Beginnings’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 16. Alexander Oparin and, independently, J.B.S Haldane first proposed a period of nonbiological evolution of spontaneous and gradually increasing complex carbon compounds that transitioned to life.

¹⁵⁴ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 180.

Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 235. For example it is known hydrogen cyanide, a key compound in the synthesis of organic molecules, must be concentrated, through evaporation or preferably by freezing out water.

¹⁵⁵ Ehrenfreund, ‘The evolution of organic matter in space’, p. 546.

¹⁵⁶ Oro, ‘Historical Understanding of Life’s Beginnings’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, pp. 92-96.

¹⁵⁷ Oro, ‘Historical Understanding of Life’s Beginnings’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 98.

¹⁵⁸ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 188.

¹⁵⁹ Hazen, Robert M., *The Story Of Earth, The First 4.5 Billion Years, From Stardust to Living Planet*, United States, Viking Penguin, 2012, p. 132.

Creating polymers of amino acids and nucleotides is not energetically favored in an aqueous environment, so energy is required in the form of activating groups attached to monomers or with condensing agents providing energy needed for bond formation.¹⁶⁰ Pier Luigi Luisi notes that although the etiology of macromolecular sequences, both proteins and oligonucleotides, is a bottleneck in origin of life research, the oligomerization of glycine up to seven units on the inside of vesicles implies environmental conditions (the high local concentration in the vesicle) were instrumental in favoring peptide coupling, even in the absence of chemical activation.¹⁶¹ James Ferris states, in the presence of water only those polymers that undergo slow hydrolysis and are bound to minerals would be expected to grow into long polymers under plausible prebiotic conditions, and chemical reactions on mineral surfaces may have provided a prebiotic route to the kinds of polymers required for the first life on Earth.¹⁶² Geoffrey Zubay claims simply changing the concentration can create thermodynamically favored reactions, i.e., peptide bond formation, which removes a water molecule, and which can proceed in an evaporated environment.¹⁶³ Robert Hazen notes that, “. . . many of life’s most vital molecular building blocks stick to virtually any natural mineral surface and though they don’t self-organize, they become concentrated on the safe protected surface of rocks and minerals and undergo what is known as template directed synthesis.”¹⁶⁴

How polymers formed in the prebiotic environment remains unknown. Research methods such as heating non-activated nucleotides to dryness, although successful in concentrating and favoring a condensation reaction, does not mimic the probable prebiotic aqueous environment. On the other hand, clay and mineral surfaces can concentrate and catalyze reactions otherwise unfavorable in the dilute aqueous environment. These few examples point to the critical importance of mechanisms for

¹⁶⁰ Ferris, ‘From Building Blocks to the Polymers of Life’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, pp. 116-117.

¹⁶¹ Luisi, *The Emergence of Life*, p. 64.

¹⁶² Ferris, ‘From Building Blocks to the Polymers of Life’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, pp. 119-120. James Ferris further states the chain length achieved depends on the competing rates of polymer formation and polymer hydrolysis.

¹⁶³ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 174. Ferris, ‘From Building Blocks to the Polymers of Life’, in Schopf, J. William (ed.), *Life’s Origin, The Beginning of Biological Evolution*, p. 121. RNA oligomers have been synthesized by binding to, and polymerizing on, montmorillonite clay.

¹⁶⁴ Hazen, *The Story Of Earth, The First 4.5 Billion Years, From Stardust to Living Planet*, p. 138. Robert Hazen states, it is recognized these processes may involve a degree of contingency, noting: “They often cooperate and yield complex surface structures of their own that may promote even more adsorption and more organization; and that wherever the prebiotic ocean contacted minerals, highly concentrated arrangements of life’s molecules were likely to have emerged from the formless broth”.

enhancing proximity of reactants, acting as surrogates of gravity, for creating more complex molecules.

Thermodynamic and kinetic factors were important in determining which chemical reactions were favored.¹⁶⁵ The products of these reactions generally resulted in more complex molecules. It is believed that the first reactions of organic chemistry were under thermodynamic control.¹⁶⁶ Further advancement of organic complexification was likely under thermodynamic and kinetic control, where processes were contingent and deterministic.¹⁶⁷ Reactions, organic and inorganic, were endothermic or exothermic and the survival of the minerals and molecules depended on the stability of those materials in relation to their local environment.¹⁶⁸

Self-reproduction, (a statistical process of making very similar things, i.e., cells), and self-replication (making exact copies, i.e., molecules) are a manifestation of one of the components of advancing complexity: the net volume of animate matter shall be maximized. Self-reproduction is believed to be the main motor for the development of life, notes Pier Luigi Luisi.¹⁶⁹ He further comments that, autocatalytic self-replicating processes are not rare but rather enjoy a degree of generality in the world of chemistry, and self-replication is no longer believed to be one of those mysterious processes considered the monopoly of living matter.¹⁷⁰ However, Luisi states self-replication in the prebiotic environment has to respect realistic concentration and rate constraints.¹⁷¹ Still, within a plausible prebiotic environment the method of creation of macromolecular sequences, and, importantly, specific sequences that convey information as opposed to simple polymerizations remains a mystery, however, the importance of concentrating

¹⁶⁵ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 189.

¹⁶⁶ Luisi, *The Emergence of Life*, p. 56.

¹⁶⁷ Luisi, *The Emergence of Life*, pp. 52, 69-70, 74. Zubay, *Origins of Life on the Earth and in the Cosmos*, p.189. "The first living organisms must have been the product of a multistep process, developments must have proceeded in a direction that presented a kinetically favorable situation for synthesis of a mixture of products that somehow was sufficiently stable to persist until the next step was taken", notes Geoffrey Zubay.

¹⁶⁸ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 181-182. For example, the amino acids demonstrate a range of stability; sugars are unstable; purines and pyrimidines are more stable than glucose; while fatty acids are very stable once formed.

¹⁶⁹ Luisi, *The Emergence of Life*, pp. 129-130, 132. Pier Luigi Luisi states, ". . . with self-reproduction (as soon as the rate of self-reproduction is larger than the rate of decay), an increase in concentration of this structure would be possible", noting further that for two reactants to form a new species requires there to be a significant amount of reactants to overcome the effect of diffusion; and the real difficulty arises when spontaneous decay is introduced.

¹⁷⁰ Luisi, *The Emergence of Life*, pp. 129-130, 153. Self-replication occurs with many chemical families including nucleic acids, formose reaction, peptides, micelles and vesicles.

¹⁷¹ Luisi, *The Emergence of Life*, p. 153.

reactants remain essential to the process.

Pier Luigi Luisi emphasizes: “There are quite a few processes that bring about an increase in molecular complexity, the general term of such processes being self-organization. Some of these processes are under thermodynamic control, i.e., occurring with a negative free energy change (micelle formation); and there are also self-organization processes that are not spontaneous, being under kinetic control (polymerization reactions)”, the ultimate goal of which is to “. . . guarantee the complexity of the biological structure.”¹⁷² However, it is recognized that methods of enhancing proximity of reactants and products in the prebiotic world were needed to explain metabolism before enzymes.¹⁷³ Organic chemistry advanced in the creation of more complex molecules and likely more complex rudimentary systems chemistry before crossing the animate divide. Organic complexification, along with non-organic complexification, advanced under the influence of gravity and its surrogates by concentrating reactants, and the electromagnetic force and other forms of energy driving endergonic reactions.

It is unknown how far organic complexity advanced and was maintained in variety, volume, and level of complexity in the prebiotic environment.¹⁷⁴ However, mineral complexity gradually did increase “. . . from only about a dozen minerals in the dust and gas that made our Solar System to more than forty-five hundred known mineral species on Earth today, two-thirds of which could not exist in a non-living world . . .”; as a result of the Great Oxidation Event, notes Robert Hazen.¹⁷⁵

Organic molecular complexity exceeded the level achieved in the ISM but eventually reached a limit on the pre-animate earth. Why was there a limit to the level

¹⁷² Luisi, *The Emergence of Life*, p. 85.

Luisi, *The Emergence of Life*, pp. 87, 100. Pier Luigi Luisi remarks, (in agreement with Peter Corning), “. . . ordered structures are thus a kind of by-product of the overall increase in entropy (disorder)”.

¹⁷³ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 180-181.

¹⁷⁴ Kwok, *Organic Matter in the Universe*, p. 6.

Luisi, *The Emergence of Life*, pp. 10-11, 52-57. Important questions remain including: How was the chirality of isomeric molecules determined?

Luisi, *The Emergence of Life*, pp. 50-52. How were the twenty amino acids of animate matter chosen?

Luisi, *The Emergence of Life*, pp. 50-51. How were the specific building blocks of nature chosen?

Luisi, *The Emergence of Life*, p. 65. How did oligomeric constructions of amino acids and nucleic acids progress?

Orgel, Leslie E., “The Origin of Biological Information”, in Schopf, J. William (ed.), *Life's Origin, The Beginning of Biological Evolution*, Berkeley and Los Angeles, University of California Press, 2002, p. 140. How was information encoded in the molecules of life? (In spite of these obstacles, complexity advanced in degree, variety, and net volume and persisted before the animate divide was crossed, although the extent each of these descriptors of complexification achieved is unknown).

¹⁷⁵ Hazen, *The Story of Earth, The First 4.5 Billion Years, From Stardust to Living Planet*, New York, Viking, p. 201.

of organic complexity attained and maintained in compound variety, variety of interactions, degree of complexity, and net volume in the preanimate environment? Why did further evolution of inanimate organic complexity require transitioning to animate matter, physically defined as contained within the plasma membrane, for molecular complexity to continue its advance? Importantly, why was the transition to animate matter necessary for systems chemistry to become robustly manifest? In the preanimate environment through concentrating mechanisms increasingly advanced molecules, chemical pathways, and perhaps rudimentary systems chemistry would be created and persist at a level permitted by the environment and would degenerate to molecules and systems of lower complexity absent a favorable environment and energy flux. Without protection they would not persist. Chemical pathways of increasing complexification would occur only if proximity of reactants could be maintained and those reactants and products protected. Although complexity of organic matter was increasing in local environments like Earth by the forces and mechanisms proposed, the balance of creation and destruction would define the level of complexity attained. Once the ceiling of complexification of the abiotic organic environment was achieved complexification of organic matter halted. A new, more tolerable environment to foster, concentrate, and protect complex organic matter was needed. An environment favoring the concentration and protection of increasingly complex molecules would permit advancement of organic complexification of molecules and systems by preventing dilution of reactants.¹⁷⁶ The creation of the cytoplasmic environment by the thermodynamically favored construction of the plasma membrane perhaps in the form of micelles, reverse micelles, and vesicles allowed this transition.¹⁷⁷

Summary of inanimate complexification

Observing the universe from its origin shows complexity, variety, and quantity of elements advance under the influence of gravity and its surrogate mechanism. Molecular complexity, variety, and net volume of complex compounds advance under the influence of gravity, its surrogate mechanisms, and the electromagnetic force. The level of complexity achieved in an environment is determined through a balance of these forces and mechanisms of creation and the tendency for molecules to deteriorate to less complex forms. Deterioration of complex molecules is anticipated if they are created by endothermic reactions and are under kinetic control. Other examples of complexification such as the crystallization of diverse mineral species on our planet

¹⁷⁶ Kaufman, *At Home in the Universe, The Search for the Laws of Self-Organization and Complexity*, pp. 35, 66.

¹⁷⁷ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 85.

evolved in variety, complexity and quantity. The negentropic advancement of complexity was achieved through a net increase in entropy of the environment external to Earth.¹⁷⁸ Both the variety and level of non-organic and organic molecular complexity and the number, or net volume, of these molecules will be maximized. Importantly, in creating organic matter of greater complexity, turnover of new molecules of the same allowed complexity replacing those that have deteriorated is anticipated as the forces of creation and destruction interact.

CREATION OF ANIMATE MATTER

Gravity and its surrogate mechanism are required to create elements. Gravity, its surrogates, and the electromagnetic force (essential for chemistry and an energy source) create increasingly complex molecules and molecular interactions. Are these forces of nature and their surrogate mechanisms leading to the creation of inanimate (organic and inorganic) complex matter, its maintenance, maximization of the amount of complex matter, and advancement of the degree and variety of complex matter sufficient to explain the creation, maintenance, growth, reproduction, and evolution of animate matter?

With the creation of more complex organic molecules in the ISM, a state of thermodynamic or dynamic kinetic equilibrium was attained. For complexity to advance beyond that created in the ISM, a more tolerable environment was needed for advancing the complexity of organic molecules and their interactions. Earth provided that environment. The concentration of prebiotic organic molecules on Earth was primarily reflective of gravitational effects at the surface, which dramatically increased the concentration of molecules and elements compared to the ISM. It is hypothesized mechanisms that further concentrated molecules in the prebiotic environment included evaporation, freezing, and selective binding to clay or non-clay minerals, which allowed the further advancement of complexity.¹⁷⁹ In these examples the particular concentrating mechanism replaced or supplemented gravity as the method bringing molecules into closer proximity to facilitate individual reactions and, importantly, chemical pathways of increasing complexity. Any method that further concentrated, isolated from the environment, and protected complex molecules while permitting

¹⁷⁸ Chaisson, *Cosmic Evolution. The Rise of Complexity in Nature*, pp. 58-59. Eric Chaisson uses the example of a container saturated with sugar. As the system cools sugar crystals form spontaneously. Possessing order, they possess less entropy than the surrounding solution. To satisfy the second law of thermodynamics an increase in entropy greater than the decrease in entropy within the system must occur somewhere else. In this case it is the air outside the vessel that experiences the increase in entropy.

¹⁷⁹ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 181.

appropriate energy flow through the system would advance molecular complexity, and importantly, would allow the advancement of systems chemistry. For example, Nick Lane notes: “Thermal currents through microporous labyrinths of alkaline hydrothermal vents have a remarkable capacity to concentrate organic molecules including amino acids, fatty acids and nucleotides to extreme levels, thousands or even millions of times the starting concentration, by way of a process known as thermophoresis”; noting that, “. . . such interactions are a matter of concentration: any process that increases concentration promotes chemical interactions between molecules.”¹⁸⁰

A feature of animate matter is the ability to establish a far greater capacity to concentrate complex molecules and elements within a limited cytoplasmic environment and subcompartmental spaces compared to many of the mechanisms mentioned above; an idea originally proposed by Alexander Oparin.¹⁸¹ The cell membrane exaggerates gravity’s effect by concentrating complex molecules within the cytoplasm, preventing dilution of reactants, thus favoring kinetic autocatalytic reactions.¹⁸² Stuart Kaufman’s theory for the creation of life depends on a defined cellular environment that concentrates a variety of molecules. He proposes, “. . . when a collection of chemicals contain enough different kinds of molecules (some of which will act as enzymes), a metabolism will crystallize from the broth”, further proposing, “. . . the rate of chemical reactions depends on how rapidly the reacting molecular species encounter one another - and that depends on how high the concentrations are . . . matter must reach a certain level of complexity in order to spring into life” and that, “. . . such self organization may have made the emergence of life well-nigh inevitable.”¹⁸³ Translated to non-biological terms, a new level of complexity in net volume, variety, and degree of complex matter and complexification of their interactions will be attained and maintained based on the dynamic kinetic equilibrium of the system, just as occurs with non-organic complexification. This strategy comports with three components of complexification proposed: complexity will increase in volume, variety, and degree.

The creation of reverse micelles, micelles, and vesicles are thermodynamically

¹⁸⁰ Lane, *The Vital Question. Energy, Evolution, and the Origins of Complex Life*, p. 110.

¹⁸¹ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, pp. 35, 66.

¹⁸² Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, pp. 34-35.

Luisi, *The Emergence of Life*, p. 75. Pier Luigi Luisi notes, “. . . vesicles . . . have facilitated intermolecular reactions mechanisms and also, through vesicles fusion, [there is] enrichment of the initial metabolism.” (Exaggerating the effect of gravity by confining complex molecules within a cellular membrane, the potential for creating complexity increases significantly).

¹⁸³ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, pp. 45,67,43.

avored and the emergence of compartments is the first structural prerequisite for the living cell.¹⁸⁴ Vesicles are bi-layered and form from fatty acids or phospholipids with the hydrophobic ends being positioned internal to the outer hydrophilic ends. Phospholipids make up most biological membranes and are made by complex enzyme processes, therefore are not prebiotic.¹⁸⁵ Vesicles are different in many ways from micelles and reverse micelles and these differences may have been important in the transition to animate matter.¹⁸⁶ The spontaneous prebiotic formation of vesicles in a cell-like bilayer structure that segregates different types of solutes of prebiotic origin that can grow and self-reproduce is recognized as extremely important in the transition to animate matter.¹⁸⁷ Interesting physico-chemistry processes are being discovered. For example, when surfactant is available larger vesicles grow faster than smaller vesicles. When RNA is entrapped the osmotic pressure on the vesicular membrane drives the uptake of additional membrane components. These examples result in emergent properties suggestive of Darwinian evolution.¹⁸⁸ “Thus, in the increase in self-organization that goes from micelles upwards, once the level of the double layer vesicles is reached, the physical characteristics of life are already encountered (membranes that cannot be easily permeated by external solutes and refuse to comply with the laws of chemical equilibrium)”, notes Pier Luigi Luisi¹⁸⁹

Micelles’ emergent property is the creation of an internal environment.¹⁹⁰ The boundary, a semipermeable spherical closed membrane discriminates the cell from the medium and is recognized as a common denominator that allows discernment between living and non-living.¹⁹¹ Autopoiesis is defined as a system capable of sustaining itself

¹⁸⁴ Luisi, *The Emergence of Life*, p. 187. Luisi, *The Emergence of Life*, p. 192. The first example of self-reproduction was with reverse micelles. Luisi, *The Emergence of Life*, pp. 190-195. Reverse micelles can encapsulate enzymes and nucleic acids and are dynamic in being able to fuse and thus exchange material with other micelles.

¹⁸⁵ Luisi, *The Emergence of Life*, p. 206. Luisi, *The Emergence of Life*, p. 209. However, straight chain fatty acids do form stable vesicles if they can be produced prebiotically. There is evidence they can be synthesized under experimental interstellar conditions. They have been found in the Murchison meteorite.

¹⁸⁶ Luisi, *The Emergence of Life*, pp. 214, 228-230.

¹⁸⁷ Luisi, *The Emergence of Life*, pp. 212, 228. Luisi, *The Emergence of Life*, pp. 233-234. The presence of a vesicle accelerates the formation of new vesicles, known as the matrix effect, by a template effect where new vesicles are of the same size. Luisi, *The Emergence of Life*, p. 237. The reproduction of vesicles of a given size range is considered possibly beneficial in the origin of life in ensuring a constancy of physico-chemical and biological properties over subsequent generations.

¹⁸⁸ Luisi, *The Emergence of Life*, pp. 238-239.

¹⁸⁹ Luisi, *The Emergence of Life*, p. 241.

¹⁹⁰ Luisi, *The Emergence of Life*, p. 115.

¹⁹¹ Luisi, *The Emergence of Life*, pp. 155, 157.

due to an inner network of reactions that regenerates the system's components.¹⁹² Pier Luigi Luisi further notes, “. . . the autopoietic system and the environment change in a congruent way . . . all changes and adaptations serve to the maintenance of the structure's identity.”¹⁹³ Autopoiesis is a manifestation of the broad definition of advancing complexity wherein the level, variety, and degree of complexity of the living system will be maintained commensurate with the environment. The logic of autopoiesis and life in general is directed towards satisfying the requirements of the numerous descriptors of complexification proposed.

Top-down theories on the creation of life, such as Stuart Kaufman's theory, benefit most directly from the emergent qualities of the cytoplasmic environment, created by construction of a cellular membrane. Confining and concentrating complex molecules within an appropriately sized cytoplasmic volume facilitates autocatalytic processes and systems chemistry.¹⁹⁴

Creation of the cell explains the emergent quality of 'self'. Life must remain separate from the higher entropy environment for the persistence of 'self'. In absence of this separateness life cannot exist, evidenced by the gradual metabolic decay of prokaryotic cell free extracts.¹⁹⁵ Interestingly, this separateness imbues the system with our biocentric view the system is striving to survive as the components of complexification are realized by the forces and mechanisms proposed; and at the most fundamental level survival is revealed to be precisely synonymous with maintaining complexity at a level permitted by the environment.¹⁹⁶

Countless examples demonstrate the importance of maintaining precise proximity relationships and concentration gradients of molecules and atoms for advancing and maintaining the complexity of animate matter.¹⁹⁷ Highlighting the criticality of this observation is that in the absence of highly specific proximity relations of molecules and atoms, and the lack of appropriate concentrations of molecules and atoms within

¹⁹² Luisi, *The Emergence of Life*, p. 158.

¹⁹³ Luisi, *The Emergence of Life*, p. 167.

¹⁹⁴ Kaufman, *At Home in the Universe. The Search for the Laws of Self-Organization and Complexity*, pp. 34-35. (Confining molecules within a cellular environment, in addition to enhancing the effect of gravity, also diminishes the chance of their destruction by establishing a favorable environment for complex molecules to exist).

¹⁹⁵ Regis, *What Is Life?*, pp. 55, 139.

¹⁹⁶ Luisi, *The Emergence of Life*, p. 166. Pier Luigi Luisi concludes, “. . . autopoiesis of each living system is a complex of circular interactions within its own environment . . . viewed as a continuous flow of mutual and coherent changes that have the aim of maintaining the equilibrium of self identity”.

¹⁹⁷ (Every critical physical and functional component within [and outside the cytosol for that matter] depends on precise proximity and concentration considerations. This is self-evident and hardly requires mentioning).

compartments and across membranes, the ability to maintain, grow, and maximize the variety and level of complexity fails resulting in destruction of animate matter.¹⁹⁸ Examples of the importance of concentration and specific proximity considerations include the spatially precise dynamic interaction of component polypeptides in the formation and function of enzymes¹⁹⁹; maintaining concentration of enzymes and reactants to facilitate the maintenance of complexity²⁰⁰; maintaining the relation of proteins of the electron transport chain embedded in the mitochondria inner wall at precise angstrom dimensions to assure efficiency of the electron transport mechanism for harvesting energy to create ATP²⁰¹; creation of potential energy through maintenance of electrochemical gradients²⁰²; maintaining the appropriate level of complexity (metabolism), growth and reproduction (increase in the net volume), and variety (evolution) of animate matter based on animate matter's relation to the environment through precisely regulated three dimensional transmembrane signaling mechanisms, and transport mechanisms for influx and removal of various elements and compounds.²⁰³

Enzymes are powerful surrogates of gravity exceeding the concentrating effects of the cytosol by bringing molecular species into proximity in a highly specific relationship to facilitate the rate of reaction in the maintenance and or advancement of molecular and systems chemistry complexification.²⁰⁴ It is the summation of anabolic or

¹⁹⁸ Regis, *What Is Life?*, pp. 55, 139.

¹⁹⁹ Cooper, Hausman, *The Cell. A Molecular Approach*, p. 338. Enzymes perform the vital task of lowering activation energies and exponentially increasing the rate of reactions, and when coupled to ATP consumption they facilitate thermodynamically unfavorable reactions resulting in creation of molecules of greater complexity.

²⁰⁰ Zubay, *Origins of Life on the Earth and in the Cosmos*, p. 119. Functionally related enzymes are located within a) the same subcellular compartment, b) components of a multi-protein complex, or c) as components of membranes.

²⁰¹ Lane, *The Vital Question. Energy, Evolution, and the Origins of Complex Life*, pp. 239-241. Nick Lane highlights the critical importance of maintaining precise distances at the angstrom level of the proteins of the electron transport mechanism. He notes electrons hop by a process known as quantum tunneling between protein centers and that the distance between each center is critical as quantum tunneling will only occur over very short distances of less than around 14 angstroms, noting: "Redox centers placed further apart might as well be infinitely distant, as the likelihood of electrons hopping between them falls to zero".

²⁰² Cooper, Hausman, *The Cell. A Molecular Approach*, pp. 448-449. The selective concentration of atoms and molecules across the inner impermeable membrane of mitochondria facilitates transport of metabolites into and out of the matrix against their electrochemical gradient and drives ATP production.

²⁰³ Cooper, Hausman, *The Cell. A Molecular Approach*, p. 70.

²⁰⁴ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 131, 139. Importantly, molecular species may either be constructed or destroyed, chemical energy may be either consumed or generated through enzymatic reactions based on the overriding necessity for the maintenance of unicellular or multicellular

catabolic pathways that serve the maintenance or growth of animate matter, not individual reactions occurring within those pathways.²⁰⁵

The logic of the metabolic machinery (autopoiesis) is to promote and maximize the component definitions of complexification, and is driven forward by the forces and mechanisms proposed. It is difficult and peculiar to accept, without attaching a cognitive element that echelons of advancing logistical strategies exist and then evolve as organic matter crosses the animate divide. The classic signaling networks we associate with autopoiesis were probably present in simpler forms before animate matter. Therefore, the enigma of autopoiesis is best understood by abandoning any biocentric, anthrocentric, or cognitive overlay, accepting logical processes exist in isolation of cognition. Distilling these processes to their most fundamental functional level, it is clear they exist simply to promote advancement of the components of complexity by the forces and mechanisms proposed.

It is important to understand complexification in its many guises, and how the descriptors of complexity compiled earlier relate to each other when speaking of animate matter, as when considering inanimate matter. For example, one component of complexification, maintaining a complex system, (as with endoliths), may be prioritized over other descriptors, such as advancing the degree and variety of complexity or advancing the net volume of complex matter, which may have lower priority. Contrariwise, when opportunity, energy, and substrate are available for advancing the net volume and or variety and level of complexity then these descriptors of complexification will assume priority resulting in population growth and or evolution.²⁰⁶ All descriptors of advancing complexity apply to animate complexification, i.e., maintaining, and maximizing the volume, variety, and level of complexity (the animate equivalent of metabolism, growth, reproduction, and evolution). These descriptors, whether applied to the inanimate or animate world, are closely coupled to

life. Anabolic and catabolic pathways are regulated by the energy status of the cell based on the ratio of ADP to ATP and pathways become the method of advancing and maintaining complexity.

²⁰⁵ Zubay, *Origins of Life on the Earth and in the Cosmos*, pp. 120-121.

Cooper, Hausman, *The Cell. A Molecular Approach*, p. 177. The classic signalling networks that provide the logic of the metabolic machinery in advancing complexification include negative feedback, positive feedback, feedforward relay, stimulatory crosstalk, and inhibitory crosstalk.

²⁰⁶ (An example of derangement of the priorities in advancing complexity resulting in the premature destruction of a multicellular organism is malignancy. In this scenario one descriptor of advancing complexity – growth – has been prioritized over another descriptor – maintenance – resulting in the premature destruction of the entire system. In a similar fashion even unicellular organisms can misprioritize the descriptors of advancing complexity by emphasizing growth over maintenance resulting in the premature destruction of the entire community through growth and reproduction that exceeds the available energy and available organic and inorganic precursors necessary for that growth).

each other and to the environment. Life's goal or purpose is indistinguishable from advancing complexity of any material system. Systems will increase in net volume, variety, and degree of complexity and will be maintained commensurate with the constraints of the environment.

SUMMARY

Complexity of matter increases under the influence of gravity and the electromagnetic force. Complexity will be created, the degree and variety of complexity and net amount of complex matter will be maximized, and, importantly, complexity will be maintained proportionate to the thermodynamic stability and dynamic kinetic stability of complex matter within a local physical environment. These observations on the evolution of complexity in general when applied to characteristics of animate matter strike a common chord. Animate matter behaves very much the same as inanimate matter when considered from the ahistorical view of the creation, maximization of the degree and variety of complexity, maximization of the net amount of complex matter, and the maintenance of complexity.

From this ahistorical outlook the creation of animate matter is explained by the interaction of two forces of nature with matter. Thermodynamic and kinetic control of reactions, organic chemistry, systems chemistry, autocatalysis, emergent phenomenon of autopoiesis, and contingency will ultimately define this transition from the historical perspective. However, the consequence of this interaction, *complexity*, will be perpetually driven forward in one or many of its guises. The animate or inanimate manifestation of advancing complexity will be driven towards maximizing the net volume, degree, and variety of complex matter in a myriad of combinations reflective of the local milieu, which will be maintained at a maximum level dependent on the environment.

The evolution of increasing complexities, varieties and net amount of animate matter mirrors increasing complexities, varieties, and net amount of inanimate complexity of, for example, the physical earth, and the organic complexity of the ISM and the prebiotic earth. Transition to life is predicted based on this mechanism and once life is established, a continuous path of increasing complexity, variety, and net volume of complex matter, and maintenance of complexity as allowed by the environment is expected. At the most fundamental level it is the interaction of gravity and its surrogates (creation of the cell, internal membranes, and enzymatic reactions) and the electromagnetic force (and other energy sources such as chemical energy) interacting with animate matter that drives the advancement of increasing complexities and varieties of animate matter. All of life's unique characteristics are better understood

employing the broad definition of complexification proposed.

Consequently, because the variety and degree of complexity must be maximized, the interaction of gravity and the electromagnetic force with animate matter provides the motive force for the evolution of species, as niches will be filled if an environment is tolerable.²⁰⁷ When environments change opportunities may arise for advancing the variety and degree of complexity. Advancing the variety and degree of complexity of life systems, that is, Darwinian evolution, is consistent with this interaction.²⁰⁸

Because the net amount of complex matter will be maximized, the engine behind unicellular and multicellular organism growth and reproduction becomes another expression of the interaction of matter with gravity, its surrogates, and the electromagnetic force. This interaction promotes maximizing the net amount of complex matter. Maximizing the net amount of animate matter is achieved through growth and reproduction absent any increase in the degree and variety of complexity of specific animate matter, i.e., creation of new species.

Finally, maintaining animate complexity at a level allowed by the local environment is synonymous with metabolism. At the most fundamental level the DNA repair enzyme cited above is performing according to the dictates of the interaction of matter with gravity and its surrogates, and the electromagnetic force and not the *élan vital* in the classical sense.

The '*élan vital*' of life's creation, metabolism, growth, reproduction, and evolution is defined entirely through the physical universe. The evolution of increasing complexities, varieties and net amount of animate matter mirrors the increasing complexities, varieties, and amount of inanimate matter of, for example, the organic complexity in the ISM, the prebiotic organic earth, and the physical inorganic earth. The interaction of gravity and the electromagnetic force with matter is the mechanism for advancing complexity and becomes peculiarly and uniquely manifest when the threshold is crossed to animate matter where the cytoplasmic environment created by the plasma membrane becomes a potent surrogate of gravity in greatly enhancing the

²⁰⁷ (Advancing the variety and degree of complexity of animate matter is intimately tethered to the environment. Although the cell is a distinct separate entity, the degree of complexity achieved reflects this relationship, just as does the degree of complexity of non-organic and preanimate organic matter. The cell is intimately related to the environment through a variety of mechanisms such as cell membrane signaling of the conditions of the environment and the exchange of metabolites with the environment. Interaction with the environment will determine what the cell will do in regulating the metabolism, growth, reproduction, and evolution for the ultimate purpose of maintaining at a maximum the quantity, level and variety of complexity permitted by the environment. But that relationship is fundamentally the same for non-animate organic matter).

²⁰⁸ Luisi, *The Emergence of Life*, p. 9.

proximity of cellular matter, at the same time imbuing the system with the subjective quality of self.

CONCLUSION

To sum up, this paper has explored why life exists by focusing on how the evolution of life is crucially related to the notion of complexity. By employing a comprehensive definition of complexity and describing the forces and mechanisms that promote complexification, this paper has shown how complexification affects both sides of the animate-inanimate divide.

The interaction of two forces of nature with matter generally serves to increase the complexity of matter. Specifically, elemental complexity advances when subjected to gravity and molecular complexity increases when subjected to gravity and the electromagnetic force. The degree, variety, and amount of complexity created and maintained in an environment reflects a balance between this mechanism and the tendency of complex systems that are far from thermodynamic equilibrium and are under dynamic kinetic control to deteriorate. Separation from the environment through the creation of the plasma membrane is essential to augment the gravitational effect of increasing the concentration and proximity of highly complex organic molecules and to allow the advancement of systems chemistry and autopoiesis. Importantly, the cell imposes the anthropocentric concept of 'self'. Life's 'purpose' becomes a manifestation of optimizing all the components of complexification of the animate system, in particular its maintenance. When these defining qualities fail animate matter will not persist.

Nevertheless, the creation, maintenance, and maximization of the net amount, variety, and degree of complex matter occur similarly with both inanimate and animate matter. When disengaging from our bio-centric view, it is evident that the creation and maintenance of animate matter, maximization of the variety, degree, and the net amount of animate matter, is identical to the inexorable process of increasing complexity of all matter under the above-discussed mechanism. When considered from an a-biological perspective animate matter is simply an extremely complex and concentrated system of organic matter, which is maintained (metabolizes), can increase in net volume (reproduces and grows), and can increase in the degree and variety of complexity (evolves) by remaining isolated from its higher entropy environment.

Animate matter can occur under favorable conditions anywhere in the universe. When gravity, gravity's surrogates (the concentrating effect of the plasma membrane and enzymes), and the electromagnetic force (essential for chemistry and often the energy source) cause the creation, maintenance, growth, and advancement of the

complexity of an animate system, we call these processes creation, metabolism, growth, reproduction, and evolution. These processes appear purposeful because they are manifest through compartmentalization within a plasma membrane so as to showcase the emergent quality we call 'self'. But this merely reflects our anthropocentric prejudice.

The purpose, if one chooses to use this concept, of the interaction of gravity and the electromagnetic force with matter, reduced to its most fundamental level and applicable to animate and inanimate matter alike, is to create, maintain, grow, and evolve a complex system through maximization of the volume, degree, and variety of matter of that system. When considering the phenomenon of life through the mechanism proposed, the question: 'Why is there life?'; the more anthropocentric question: 'Why are we here?'; and the mystery of life become less opaque. The historical transition to animate matter will likely have numerous commonalities throughout the universe due to the dynamical nature of carbon, and because the essential component in creating life - the creation of the cellular environment - is thermodynamically favored. Although there is no élan vital in the creation and maintenance of life in the classic sense, gravity, gravity's surrogates, and the electromagnetic force drive this process. Under appropriate environmental circumstances life becomes a probable outcome whenever and wherever matter is perpetually subjected to these forces.

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