The Conditions of Emergence: Towards a Feminist Philosophy of the Origins of Life

by

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Duke University

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Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor
of Philosophy in the Graduate Program in
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ABSTRACT

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Abstract

This dissertation explores the limits of feminist theory in terms of what questions it can address, and does this by reimagining the relation feminist theory and late nineteenth and twentieth-century continental thought can have with scientific research concerning the origins of life. I argue that a phallocentric scientific and theoretical framework—in which one term, one mode of being, is privileged and becomes the "universal" at the expense of all others—is incapable of addressing the emergence of life out of matter on Earth. A phallocentric theory of the origin of life posits a hierarchy between life and matter and understands them as fundamentally opposite to each other. In such a framework, life and matter are always external to one another, and matter is denigrated at the expense of life. In creating a division between matter and life, phallocentric approaches to the origins of life create a dilemma for themselves because they need to pinpoint exactly when life emerges, in other words they need to answer and explain exactly when "inanimate" matter is animated or penetrated with a *logos* of life. Building on the feminist science studies tradition that examines the relation between metaphor and science, *The Conditions of Emergence* studies how certain strands of origins of life research are beginning to question whether scientific work rooted in metaphors of light, energetic stasis, and autonomous self-birth can attend to the question of how cellular life first emerged from matter somewhere between 3.8 and 4.2 billion years ago. In lieu of these metaphors, theories of origin concentrating on deep-sea vents re-embed life's cellular beginnings within a geochemically volatile ancient Earth through metaphors of darkness (rather than light) and gestational birth in inorganic wombs (rather than within narratives where a cellular body brings itself into being). I argue that thinking about and trying to conceptualize a dark proto-intrauterine space that is bioenergetically never at

rest and rooted within the geochemical forces of the Earth as the origins of cellular life generates, perhaps for the first time, a feminist philosophy of life.

The relation between matter and life is the litmus test I use for what kinds of contemporary scientific research—while not explicitly feminist themselves—have potential implications for a feminist philosophy of life. I read contemporary origins research through the writings of a number of theorists or philosophers, such as Henri Bergson, Ilya Prigogine, Gilbert Simondon, Raymond Ruyer, Luce Irigaray, and Elizabeth Grosz. Across four chapters, I engulf key debates in origins of life studies—the evolution of metabolism, the invention of the first cellular membranes, and the birth of genetics, and the beginning of heredity—in a far-from-equilibrium fluid milieu that creates the possibility for their emergence.

Dedication

To Liz, MD, and Milo.

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Acknowledgements

This dissertation, as well as my larger graduate school journey, could not have been completed without my parents' unshakeable support. I am in no way the daughter they expected, but they have shown me that they will be by my side through any challenge I face. I am also grateful to have been able to grow and develop a new relationship with my little brother over these past seven years. I write this dissertation in loving memory of my *masi*, who passed away from ovarian cancer during my fourth year.

My dream of going to graduate school would not have started if it were not for the support of my undergraduate mentors in the Women's and Gender Studies department at Rutgers University: Ed Cohen, Brittney Cooper, and Kyla Schuller. Thank you for all you taught me, and for your kindness and compassion. I hope this dissertation makes you proud.

I am grateful to have a dissertation committee that supported and encouraged an abstract project about feminist theory and the origins of life. I could not dream of a better advisor than Elizabeth Grosz. Mark Hansen's support as co-supervisor, as well as DGS, proved vital for me to successfully complete writing during my final year. I have felt a deep connection and resonance with Kate Hayles, especially when we were both physically away from Duke, whether it was at SLSA or the *science*humanities school. Finally, I am thankful for the mentorship and guidance Priscilla Wald has given me on things big and small.

I would like to thank The Program in Literature, The Program in Gender, Sexuality, and Feminist Studies, and The Graduate School for their financial support. The last year of writing my dissertation was greatly enhanced by the opportunity to TA for Patrice Douglas during the Fall 2019 semester. I am also glad to have had the chance to work with Luciana Parisi during the Spring 2020 semester, whose research and teaching have been a generative resource to think with.

Thank you to my friends at Duke who I have laughed, lamented, thought, written, and grown with: Kimberley Dimitriadis, Patricia Bass, Julien Fischer, Eylül İşcen, Anastasia Kārkliņa, Cole Rizki, and Kena Wani.

Thank you as well to my friends and colleagues who have read drafts of this dissertation: Jessica Gokhberg, Lucas Power, Cole Rizki, and especially MD Murtagh. Your feedback and assistance have been invaluable.

Over this past decade, my world and its intellectual horizons have been profoundly shaped by the work of Elizabeth Grosz. Thank you for the philosophical lineage you have shown and taught me, your mentorship, and your unwavering support.

No one has taught me more about the non/human than Milo. His commitment to living life to the fullest and on his own terms has been a source of inspiration for how I might live mine. Our walks together have incited ideas that have become central to this project.

This dissertation would not have been completed without MD Murtagh, who has seen this project in all of its stages—from in its most virtual and elementary form when I was an undergraduate thinking about viruses and the nature of life—to its long gestation and final actualization during this last year. Thank you for being such an astute and careful reader of my work. The best part of graduate school has been thinking, living, traveling, and growing with you.

1. Introduction

"Mankind likes to put questions of origins and beginnings out of its mind: must one not be almost inhuman to detect in oneself a contrary inclination?"
—Friedrich Nietzsche, *Human, All Too Human: A Book for Free Spirits*

1.1 Towards a Feminist Philosophy of Life and Birth

Philosophy, as it has been practiced in the West, is in many ways ill-suited to studying life. According to feminist philosopher Val Plumwood, following Plato, we have inherited a philosophy that is adept at the study *of death*, one that values another realm of timeless Forms over and above the living world and the becomings within it. What our senses intuit are lies and the things that are subject to change are derivative denigrations—in short, "the living world of nature is called a tomb" rather than a rich reservoir for thought.[1] While language and metaphors rooted in reproduction and the maternal body have often been appropriated by philosophy,[2] the biological body, especially the (cis)female body, is seen as corrupt and decaying. In this way, the event of birth is denigrated. This denigration and dismissal of the materiality of birth is peculiar, because birth, as Fanny Söderbäck reminds us, is arguably the *one* experience that all of life shares: "If (male) philosophers for millennia have been concerned with death, and if death is the one event those writing about it have yet to experience, birth is perhaps the only experience we

[1] Val Plumwood, *Feminism and The Mastery of Nature* (New York and London: Routledge, 1993), 97, citing Plato *Phaedo*, 226)
[2] See, for example, Page duBois, "The Platonic Appropriation of Reproduction," in *Feminist Interpretations of Plato*, edited by Nancy Tuana, 139–56 (University Park: The Pennsylvania State University Press, 1994).

all—constitutively—share, insofar as we have all been born."[3] A feminist philosophy of life would include a philosophy of birth, and would take seriously how things *begin*.

This project explores the concept of birth, but in the most extreme non-anthropocentric sense of the term. It seeks to cultivate a feminist philosophy of life, and does so by focusing on the origins of cellular life itself. This is a question that has long been understood as an insurmountable obstacle. In *The Cell in Development and Inheritance* (1896), a landmark text in the history of biology, Edmund B. Wilson notes that "the study of the cell has on the whole seemed to *widen* rather than narrow the enormous gap that separates even the lowest forms of life from the inorganic world."[4] The sophistication we witness within a single cell makes it difficult to understand the origins of this sophistication. The gap between the inorganic world and the cell seems insurmountable because the cell is a clearly bounded autonomous individual that can reproduce itself.[5]

This dissertation takes up the difficulty of addressing this relation between the inorganic world and the cell, and does so through origins of life research, feminist theory, and allied biophilosophies. It uses the attention to birth within feminist theory, in order to rethink the beginnings of life itself. Feminist theory has called attention to the theoretical and political devaluation of the (cis)female reproducing body,[6] and is therefore acutely attuned to the question of beginnings. This orientation within feminist theory towards beginnings makes it well suited to

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[3] Fanny Söderbäck, "Introduction: Why Birth?," *philoSOPHIA* 4, no. 1 (2014): 2.
[4] Edmund B. Wilson, *The Cell in Development and Inheritance* (London: MacMillan and Company, Ltd., 1896), 330, emphasis added.
[5] According to Donna Haraway, the development of "cell theory" signaled the "triumph of atomism of nineteenth-century biology" (*Crystals, Fabrics and Fields: Metaphors of Organicism in Twentieth-Century Developmental Biology* (New Haven and London: Yale University Press, 1972), 12).
[6] See, for example, Adrienne Rich, *Of Woman Born: Motherhood as Experience and Institution* (New York: Norton: 1976).

think beginnings in a larger, non-anthropocentric frame. (Cis)female human birth is *not* where birth *ends*—because the processes of birth only continue to be remade and complexified in our contemporary biotechnological landscape,[7] and, more pertinent to my aims here, it is also not where birth *begins*. In this project, I argue that the central concepts we associated with the corporeal process of birth that we see in the human frame have their origins in something much more ancient. This expands what questions feminist theory can address, and does so by displacing the centrality of (cis)female bodies as the center around which feminist theory must revolve. Instead, what interests me here, is what ontological forces create the conditions of the human, that permeate the human, and that therefore must *precede* the human. It thus explores and thinks with central concepts in feminist philosophy—such as birth, materiality, and life—but does by so embedding them in what Donna Haraway could call a "more-than-human" world, and in, I would add, a *pre*human frame.

1.2 Where Do We Come from? Feminist Theory and "Origin"

Feminist theorists have long been highly skeptical about "origins." As a concept, "origin" presents possible theoretical risks that need to be addressed. This is especially true when "origin" is thought in relation to science and evolution. According to Jamaican-born black feminist theorist Sylvia Wynter, an origin story rooted in Darwinian evolutionism is a particularly powerful narrative because it is singularly vast enough to cover over the biblical story of the genesis of life. Wynter elaborates on what is at stake in the concept of origin:

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[7] See, for example, Sarah Franklin, *Dolly Mixtures: The Remaking of Genealog*y (Durham and London: Duke University Press, 2007), Sarah Franklin, *Biological Relatives: IVF, stem cells and the future of kinship* (Duke University Press, 2013), and Michelle Murphy, *Seizing the Means of Reproduction Entanglements of Feminism, Health, and Technoscience* (Durham and London: Durham University Press, 2012).

> ...as humans, *we cannot/do not preexist our cosmogonies*, our representations of our origins—even though it is we ourselves who invent those cosmogonies and then retroactively project them onto a past. We invent them in formulaic storytelling terms, as "donor figures" or "entities," who have *extrahumanly* (supernaturally, but now also naturally and /or bioevolutionarily, therefore secularly) *mandated* what the structuring societal order of our genre-specific, eusocial or cultural *present* would have to be.[8]

In the cosmogonies humans invent, the origins evoked are those that often seek to account for the existing structural forces of power rooted in colonial-capitalism, and in doing so, reify the weight of present-day oppression. "Origin," by rooting itself in a hierarchical notion of difference where one mode of human being is culturally, philosophically, and politically privileged over all others, "naturalizes" (and by extension, "justifies") oppression rooted in sex/gender, and race.[9] This concretization of "difference" is especially dangerous if done using the expertise of science. Central figures in feminist science studies such as Donna Haraway have famously declared that "origin stories," particularly ones that are rooted in partrichial Judeo-Christian "truths" and narratives of "purity" should be questioned. While I do not seek to re-enthrone phallocentric origin stories, I am interested in thinking with specific strands of origins of life research that re-orient our place (as humans) in the world by attending to the complex material (that is the physical, geological, and chemical) forces that engendered our existence. It is precisely the potent power of origins stories that they can be remade and re-deployed in non-phallocentric and nonracist and non-human-centric terms. As one feminist scholar puts it, while it is crucial to remember "how traditional origin stories are used to reproduce the logics of domination by

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[8] Sylvia Wynter and Katherine McKittrick, "Unparalleled Catastrophe for Our Species? Or, to Give Humanness a Different Future: Conversations," in *Sylvia Wynter: On Being Human as Praxis*, ed. Katherine McKittrick (Durham and London: Duke University Press, 2015), 36.
[9] It should be noted that the present variations of sex/gender and race *have evolved*, and are themselves a counter to this idea that oppression can be rooted in human variations. The evolution of human beings in all their pluralities is an affirmation of difference itself—in other words, a difference without hierarchy.

positing "natural, original" gender and race differences. At the same time, it's important to read how alternative/rewritten feminist origin stories destabilize, contradict, and contest the traditional discourses of origin on their own turf. These origin stories are powerful precisely because they not only denaturalize the dominant accounts, but also because they partake of the enabling power that marks all discourse about origins."[10]

The question of where we come from is one that has captivated cultures for millennia. Because of this, a whole host of origins stories exist to make sense of this question. My focus here is how the origins of life have been narrated by science, particularly in the twentieth and twenty-first century. Even a scientific approach does not produce a definite answer. A scientific inquiry into the origins of cellular life will find no direct living trace of this event. The Earth itself is estimated to be about 4.6 billions years old. There are no geologic fossils that date back to the origins of Earth due to its inherent geophysical volatility. It took only a short period of time—a mere 200 million years—for the first oceans to form. Cellular life on Earth is thought to have emerged shortly after the birth of oceans somewhere between 4.28 and 3.77 billion years ago. There is approximately a billion year gap between the beginnings of cellular life and the oldest "biosignatures" or molecular fossils of once-living organisms. As of now, the oldest microfossils are around 3.5 billion years old. Relics older than these microfossils are surrounded by speculation and controversy. The further back in time one moves, the more muddy the scientific question of when cellular life began becomes.

This dissertation situates itself in the speculative space before cellular life emerged from matter. Given there is no direct empirical evidence from this period, scientific research on this

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[10] Cathy Peppers, "Dialogic Origins and Alien Identities in Butler's *Xenogenesis*," *Science Fiction Studies* 22, no. 1 (1995): 48.

topic is more theoretical than empirical in nature. It is within this milieu of scientific inconclusiveness surrounding the origins of life—which is, moreover, a fundamentally unknowable question—that this project exists, and it is within speculative space where I craft a feminist philosophy of life.

What I am calling a feminist philosophy of life is one where there is not a binary relationship between matter and life, where the latter is simple a +/- component to matter. Life cannot be thought as external matter—especially as an outside "animating" spark to matter.[11]

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[11] It should be noted that in this project I do not locate the concept of "life" exclusively within cellular life. Such an approach may be the general (though not universal) conceptual maneuver in origins of life research, but it is not useful for a project like mine. For one thing, whenever life is strictly defined and located, there are always bound to be exceptions. Life is too creative, too open to transformation, for any strict definition to solidly define it. This difficulty of defining life is most directly palpable in research on viruses—beings that do not have a fully autonomous existence (as they are dependent on cell metabolism and machinery to replicate) but that nonetheless are active agents within evolution, and as I chart in chapters three and four, may have had a significant role in life's beginnings. While I largely focus on the conditions that generated the possibility of cellular life, in an ontological register, life always exceeds its cellular forms. Beings such as viruses make this evident, but in a more abstract theoretical sense, we can say, with Deleuze, that life "lives" between and across inorganic and organic matter. It is a certain kind of movement that differs within itself, and thus is fundamentally open to bringing about transformation and change. The broadest definition of life put forward by NASA is that life "a self-sustaining chemical system capable of Darwinian evolution" (David Deamer and Gail R. Fleischaker, *Origins of life: the central concepts* (Boston, MA: Jones & Bartlett Publishing, 1994). Furthermore, it is becoming clear to scientists that defining life may not be possible, but also "pointless" (Leonardo Bich and Sarah Green, "Is defining life pointless? Operational definitions at the frontiers of biology," *Synthese* 195 (2018): 3919–3946). While I am concerned with the conditions of emergence of life, in this project, I refuse to define "what" life "is." My reasons are twofold. First, following Bergson, a completed definition of life is only possible in a completed reality; as long the universe endures, life cannot be defined. In Bergsonian terms, the closest characterization one could give Life is more like a *tendency,* what could also be called an orientation. Second, following Irigaray, the question what is life is inherently problematic. According to Irigaray, "the question 'what is…?' is the question—the metaphysical question—to which the feminine does not allow itself to submit" (*This Sex Which is Not One*, trans. Catherine Porter and Carolyn Burke (Ithaca: Cornell University Press, 1985), 122). In other words, it is a phallocentric question that freezes and solidifies a concept that is in fact living. Life shares something with matter, and its tendencies are an elaboration of the virtual qualities of matter. There is a unity of life at its origin, one that continues to differentiate along evolutionary lines of

Such a model is rooted in a particular kind of philosophy of equilibrium and stasis that could never generate the creative novelty that marks all of life. Their relation is instead much more complex. *The Conditions of Emergence* argues that there is a philosophical alliance between transcontinental feminist theory and contemporary origins of life research. Building on the feminist science studies tradition of examining the relation between metaphor and science, *The Conditions of Emergence* studies how certain strands of origins of life research are beginning to question whether scientific work rooted in metaphors of light, energetic stasis, and autonomous self-birth can attend to the question of how cellular life first emerged from matter somewhere between 3.8 and 4.2 billion years ago. Using other metaphors, theories of origin concentrating on deep-sea vents re-embed life's cellular beginnings within a geochemically volatile ancient Earth through metaphors of darkness (rather than light) and gestational birth in inorganic wombs (rather than within narratives where a cellular body brings itself into being). I argue that a dark proto-intrauterine space, one that is bioenergetically never at rest and rooted within the geochemical forces of the Earth, makes, perhaps for the first time, the question of how life emerged a conceptual possibility within both scientific research and a philosophy of life that is not phallocentric.

In the past two decades, feminist new materialism and feminist inquiry more broadly have destabilized the centrality of the human in at least two ways. First, the human's possibility of existence, its purported autonomy, has been challenged by a rigorous attention to the more-than-human world that helps constitute the human as such. Furthermore, the concept of *Human*, is itself a particular origin story that is born of colonial-capitalism, whose narrative construction is

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descent. This is broadest characterization I can make of life in lieu of a strict solidifying definition.

never highlighted, which gives this concept a timeless eternal presence when in fact it is always a creative and culturally variable projection.

Feminist new materialism marks a shift in how materiality is understood. The materiality that constitutes human existence can no longer be taken for granted.[12] Research in new materialism also addresses how inanimate matter entails an ontology of its own. This dissertation brings feminist new materialism's reframing of matter to origins of life research. If one of the goals of feminist new materialism is to consider how matter comes to matter, this project asks how the origins of life might bear on this question. What is meant when matter is evoked? In an evolutionary cosmological framework, one could argue that what is meant by "matter" only comprises "ordinary" matter, a small portion of what constitutes the category of matter itself.[13] Thus how does the "matter" of feminist new materialism relate to the concept of life?

I argue that concepts historically and philosophically aligned with the "maternal" generate new insights regarding such research. That being said, though this project focuses on how the "maternal" opens up new parameters to think origins, the relationship between nature as a passive, controllable "female" should be addressed. One definition or function of phallocentrism is the appropriation and subsequent disavowal of the metaphorics of femininity and maternity in order to produce a "neutral" system of thought. The feminine becomes the reservoir from which the system is constructed as well a kind of irremovable symptom or excess of the system that surfaces in a text. My method in this project is not so much a symptomatic reading of origins research;[14] it is instead an examination of how the metaphorics of sexual

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[12] Diana Coole and Samantha Frost, "Introducing the New Materialisms," in *New Materialisms: Ontology, Agency, Politics* (Durham: Duke University Press, 2011), 1.
[13] See MD Murtagh, forthcoming.
[14] This approach is championed in Luce Irigaray's work, particularly in *Speculum of the Other Woman,* trans. Gillian C. Gill (Ithaca: Cornell University Press, 1985), and *An Ethics of Sexual*

difference are explicitly used within such works. I seek to examine how concepts historically and theoretically aligned with cis-female bodies function as a positivity in research. In this project, this will range from more obvious concepts such as womb and gestation, but also less obvious ones such as maternal engines. This project also utilizes theoretical texts that challenge the idea that metaphorics of stasis, light, and vision can birth a feminist philosophy of life.

1.3 Life through Death: Light and Vision

In order to flesh out what a feminist philosophy of life could be, it is helpful to outline how we have tacitly come to understand "life" in a cultural, and even scientific, sense. To start, cultural and scientific conceptions of life have often been rooted in *light*. One such example of this is Mary Shelley's *Frankenstein*; *or, The Modern Prometheus* (1818), in which metaphors of light and electricity providing the "spark" of life abound. Shelley's novel has had an instrumental role in cultural conceptions of generating life, especially through the means of light and electricity.[15] The boundary between life and death in *Frankenstein* is not absolute, and instead is a permeable barrier between these two forces.[16] One could argue that life is wholly understood through the framework of death. Frankenstein himself notes that in order "to examine the causes

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Difference, trans. Carolyn Burke and Gillian C. Gill (Ithaca, New York: Cornell University Press, 1984). A more contemporary Irigarayan symptomatic reading is Emanuela Bianchi, *The Feminine Symptom: Aleatory Matter in the Aristotelian Cosmos* (New York: Fordham University Press, 2014).

[15] In the long eighteenth century Anglophone context, the concept of electricity animates not only natural philosophy of the period, but also the cultural and political milieu. See Mary Fairclough, *Literature, Electricity, and Politics 1740-1840: 'Electrick Communication Everywhere'* (London: Palgrave Macmillan, 2017).

[16] It should be noted that death has multiple valences in the eighteenth century. Sharon Ruston notes how medical doctors in France and England differentiated between "incomplete" and "absolute" death. The former consists of fainting, coma, or sleeping while the latter is "absolute" when there is a decaying corpse. Victor Frankenstein's many fainting spells in the novel where he goes "lifeless" adhere to the idea of "incomplete death" (Sharon Ruston, *Shelley and Vitality,* London: Palgrave Macmillan, 2005: 149).

of life, we must first have recourse to death."[17] Frankenstein's experiments reflect the scientific experiments of that era. In 1791, Italian physician Luigi Galvani was able to make the leg of a dead frog twitch through an electrical current, prompting him to put forth the idea of "animal electricity" as an innate life force distinct from "common chemistry." For Galvani, "animal electricity" accumulated in the frog leg was able to be discharged through a metal apparatus.[18] An infamous debate ensued between Galvani and Italian scientist Alessandro Volta, the latter arguing that the frog leg contraction was not due to electricity accumulated within the leg, but rather derived from the metals Galvani used on the frog corpse. Shelley was well aware of these debates regarding galvanism, and these ideas surround and inform how life might return from death in *Frankenstein*. The boundary between life and death is porous and impermanent for Victor Frankenstein:

> Life and death appeared to me as ideal bounds, which I should first break through, and pour a torrent of light into our dark world. A new species would bless me as its creator and source; many happy and excellent natures would owe their being to me. No father could claim the gratitude of his child so completely as I should deserve theirs. Pursuing these reflections, I thought, that if I could bestow animation upon lifeless matter I might in process of time (although I now found it impossible) renew life where death had apparently devoted the body to corruption.[19]

Victor Frankenstein understands life through the figure of death and brings about life by suturing together different parts of corpses in a piecemeal-like way. The question of animating life here is one of reanimation. While Shelley's novel is rarely explicitly cited by scientists,[20] the ideas about

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[17] Mary Shelley, *Frankenstein* (Barnes and Noble Press: New York: NY, 2003), 46.
[18] Marco Piccolino, "Luigi Galvani's path to animal electricity," *Comptes Rendus Biologies* 329, 5-6 (2006): 303-318; 316.
[19] Shelley, *Frankenstein*, 48.
[20] See Elbert Branscomb and Michael J. Russell, "Frankenstein or a Submarine Alkaline Vent: Who Is Responsible for Abiogenesis? Part 1: What is life–that it might create itself?" *BioEssays* 2018,40, 1700179 and Elbert Branscomb and Michael J. Russell "Frankenstein or a Submarine

reanimating life of *Frankenstein* form the backdrop of origins stories of life, especially in a cultural context. The idea of suturing together and "animating" dead, once living fragments of different bodies utilizing chemical instruments through electricity and light, culturally, and to a certain extent, scientifically, frames how the origins of life is understood.[21] While Victor Frankenstein clearly is undertaking the task of *re*-animation rather than the origins of animation, Shelley's novel nonetheless establishes a relation between life beginning with an electric spark. The beginnings of cellular life cannot be understood through a theory of life rooted in re-animation. In other words, the becoming of life does not unfold through the bringing together of already-constituted parts that are then animated with some energy source and made "alive."

In *Frankenstein* one also finds the idea that nature is a female who hides "her" secrets. For literary scholar Anne K. Mellor, marking nature as female in order for masculine scientific desire to pursue her "to her hiding places"[22] signifies the gendered construction of the novel's universe, and our conceptions of nature more broadly.[23] The gendering of nature as a passive being who hides her secrets and thus calls for a masculine pursuit, cooptation, and control has been studied by feminist scholars.[24] Though scientists may argue that such representations of nature as female and therefore passive and controllable are "simply metaphors," the question of what effects these metaphors have must still be asked. More strongly, these metaphors seem almost impossible to replace, or if they are replaced, it is by other metaphors, which we use to

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Alkaline Vent: Who is Responsible for Abiogenesis? Part 2: As life is now, so it must have been in the beginning," *Bioessays* 40 (2018): 1700182. I address both of these articles in chapter two.

[21] Shelley, *Frankenstein*, 46.

[22] Shelley, *Frankenstein*, 42; 44.

[23] Anne K. Mellor, *Mary Shelley: Her Life, Her Fiction, Her Monsters* (New York: Methuen, 1988), 115.

[24] See, for example, Londa Schiebinger, *Nature's Body*: *Gender in the Making of Modern Science* (New Brunswick: Rutgers University Press, 2004) and Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (New York: HarperOne, 1983).

think that which cannot be directly said. Take, for example what Francis Crick, one of the three people awarded the Nobel Prize in 1961 for elucidating the structure of DNA, writes in a preface to a scientific anthology called *The RNA World:*

> The recombinant-DNA revolution of the 1970s was possible because molecular biologists could use the sophisticated products of billions of years of natural evolution—the replicases, the restriction enzymes, and so forth—as precise and delicate chemical tools. These molecules were all proteins that acted on nucleic acids in one way or another. Now experimentalists...are using a combination of biochemical processes, related to nucleic acid replication, which together embody the mechanism of natural selection. These powerful tools can provide them with new and desirable RNA molecules in the laboratory while they wait. But these methods do not need whole cells, but only cellular components, they can handle many more individuals at one time and so explore the RNA "space" more quickly. The message is clear: Where possible, let Nature do the work, and if she proves a little slow, take your whip to her.[25]

Originally from the first edition of *The RNA World,* Crick's preface has been reprinted in both the second and third editions of this anthology. The editors of *The RNA World* make no comment about Crick's terminology. Nature, here, is inventive in how she creates chemical components that can be harnessed for scientific use; but in cases where Nature does not produce what is useful for science, physical violence can generate the wanted result. It would not be a leap to argue Crick's sentiments resonates with Frankenstein's attitude and approach towards nature.

My premise in this project is that metaphors of light and life, and of nature as a passive controllable female—*or even as a female* more broadly—cannot bring us closer to theorizing how cellular life may have emerged. An impossible question though this is, conceptualizing emergence becomes *theoretically* possible when we cease to understand life as something that can be engendered from death. Though nature has been rendered female in order to be exploited

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[25] Francis Crick, "Foreword to the First Edition of the RNA World," in John F. Atkins, Thomas R. Cech, and Raymond F. Gesteland, *RNA Worlds: From Life's Origins to Diversity in Gene Regulation* (Cold Spring Harbor, New York: Cold Spring Harbor Press, 2011), ix.

and controlled, this project attends to how the concepts of sexual difference open up new ways to theorize cellular life in ways that address incorporeal and corporeal aspects of evolution. Below, I outline how a feminist philosophy of life would think not rely on dead metaphors of life and light, but instead through water, darkness, tactility, and disequilibrium.

1.4 Gestation: Wet, Dark, Tactile, Disequilibrium

If one wants to craft a feminist theoretical engagement with the origins of life, how might this be done? I suggest we begin by thinking about the *conditions* of life's emergence. To focus on *conditions* is to consider "the whole affecting circumstances under which a being exists."[26] The first condition is the milieu in which life exists: water. In our contemporary political and ecological moment, the idea that "water is life" is replete with urgency.[27] If one wants to trace the significance of this idea in relation to biological processes as a whole, in what sense *is* water "life"? In *Life's Matrix: A Biography of Water*, physicist and science writer Phillip Ball provides a scientific answer to what this idea means:

> In scanning through the literature of modern molecular biology, you could be forgiven for concluding that the subject is all about proteins and genes, embodied in the nucleic acid DNA. But this is only a form of shorthand; for biology is really all about the interactions of such molecules in and with water…Biology starts with water—historically, ontologically, pedagogically.[28]

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[26] "condition," OED definition.

[27] Water struggles are occurring across the world. In the United States, the Standing Rock indigenous movement in North Dakota fighting against the Dakota Access Pipeline as well as the lead poisoned water public health crisis in Flint, Michigan are two dire emergencies. For Standing Rock, see Chas Jewett and Mark Garavan, "Water is life–an indigenous perspective from a Standing Rock Water Protector," *Community Development Journal* 54, no.1 (2019): 42–58. For Flint's water crisis, see Anna Clark, *The Poisoned City: Flint's water and the American urban tragedy* (New York: Metropolitan Books, 2018). For an international study of the right to have access to clean water, see Vandana Shiva, *Water Wars: Privatization, Pollution and Profit* (London: Pluto Press, 2002).

[28] Phillip Ball, *Life's Matrix: A Biography of Water* (New York: Farrar, Straus, and Giroux, 1999), 250.

Over the past century, the figure of the gene and the field of genetics has come to dominate how we understand the concept of life. However, evolutionary theory divorces the gene from its cellular body. This narrative is both reductive and inaccurate in how it eschews the fundamental roles of the materiality of bodies and their fluid milieus in evolution. The disregard of water's presence in biological literature makes this effacement more salient. A strict focus on genetics in the formation and evolution of cellular life involves a kind of navel-gazing that renders the forces of materiality—operating within living bodies and in the outside world—silent, passive, and lifeless. The idea that biology starts with and requires water is often subdued and ignored in this same discipline whose objects of study are only possible because of water. Ball cites two biologists who rationalize this subjugation: "When scientists publish models of biological molecules in journals, they usually draw their models in bright colors and place them against a plain black background. We know that background in which these molecules exist—water—is just as important as they are."[29] It seems as if the scientific discipline of biology consistently represents itself as something separate from, and even possible without, water. Playing no role in life, the *medium of* life is represented as a silent backdrop, a blank canvas, that simply contrasts the biomolecules of interest. This representation of water as a silent and invisible setting for life is in fact the inverse of life's current existence. Ball goes so far as to remind us that water itself is a biomolecule that creates the possibility of other biomolecules we usually associate with life: any and all biochemical components of life—nucleic, protein, or otherwise—fold themselves *into being* in relation *to* water. If it is possible to ignore the integral role of water in relation to the life

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[29] Ball, *Life's Matrix*, 250, citing Mark Gerstein and Michael Levitt, "Simulating Water and the Molecules of Life," *Scientific American* (November 1998), 100-5.

of a fully functioning mature cell, can the fluid matrix of life be ignored in processes that constitute life's beginning? In other words, how central is water, the "matrix" of life, to life's origin?

The etymological roots of "matrix" are rooted in ideas around the maternal. They trace back to "breeding female," "womb," as well as to *mater*, the root of "matter" and "mother." A matrix can also be defined as "a place or medium in which something is originated, produced, or developed; the environment in which a particular activity or process begins; a point of origin and growth."[30] Furthermore, matrix is "a supporting or enclosing structure."[31] Thus, this concept is marked with "female," "mother," "structure," "medium" as well as a point of origin. What does it mean for something to originate *in* something else? How can one think the becoming of life without considering the "medium" or "place of origin" it becomes within?

How can we deploy "the maternal" in the ways we theorize the origins of life, and how might this relate to water? Though birth from a human perspective almost always involves gestation within a cis-female body, it is important to keep in mind that the concept of "maternal" does not begin with the human. I seek to destabilize this concept by looking at its evolutionary origins four billion years ago in the first cells. As an ontological force that is necessary for life, the sedimentation of the maternal with cis-female gestational bodies can be dissolved. In doing so, the maternal can be recast as a primordial force that marks the possibility of *any* kind of cellular life to emerge. A non-anthropomorphic reading of the maternal both destabilizes its

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[30] "matrix, n.". OED Online. June 2017. Oxford University Press. http://www.oed.com.proxy.lib.duke.edu/view/Entry/115057?rskey=VqmYYl&result=1 (accessed October 26, 2017).
[31] "matrix, n.". OED Online. June 2017. Oxford University Press.http://www.oed.com.proxy.lib.duke.edu/view/Entry/115057?rskey=VqmYYl&result=1 (accessed October 26, 2017).

attachment to cis-female gestation *while* also moving us further back in time—a necessary requirement to theorize life's origins. The maternal in this reading provides the conditions for any kind of cellular life, both human and non/human. The sea is often evoked to represent the maternal, but, in fact, it is the other way around: "first comes *la mer*, then *la mére*."[32] Gestational water is ontologically prior to gestational human bodies.[33] A feminist philosophy of life must be submerged in water as its first condition of emergence.

We carry water within us, and we gestate and are birthed within an aqueous milieu. A feminist philosophy of life would therefore theorize the sea, which has an ancient relationship to life. One idea that stresses this idea is "hypersea"—a simultaneously ontological and scientific concept proposed by geologists Mark McMenamin and Dianna McMenamin. "Hypersea" is an idea that marks the new forms of life that emerged when life moved from the sea onto land 400 million years ago. It is both an "organismic" or biophysical entity that engulfs and connects all organisms "with nucleus-bearing cells (plants, fungi, and protoctists) and their symbionts" on land,[34] as well as a scientific theory, and therefore subject to experimentation and subject to falsification. It entails a novel perspective on how we understand land biota: hypersea stresses the aquatic milieu that life took for granted in the sea that it must be actively re-create in order to have a chance to survive on land.

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[32] I am appropriating this phrase from psychoanalyst Sandor Ferenczi and draw inspiration from Luciana Parisi and Tiziana Terranova's deployment of this idea ("Heat-Death: Emergence and Control In Genetic Engineering And Artificial Life." *CTHEORY* (10: 2000), http://ctheory.net/ctheory_wp/view-all/, citing Klaus Theweleit*, Male Fantasies: Women, Floods, Bodies, History* (Cambridge: Polity Press,1987: p.292).

[33] One can think with Astrida Neimanis here, who argues that "[g]estationality does not begin and end with the human, nor with a (heteronormatively inflected) female one at that. Gestationality is something we learn–something we repeat, differently–from water" (*Bodies of Water* (London: Bloomsbury, 2017), 118).

[34] McMenamin exclude bacteria from their conception of hypersea.

When it is completely submerged in an aqueous milieu, direct connections between life forms were not required; the aqueous milieu they were in compensated for this lack of distance: "[o]rganisms, which are primarily water, can interact at arm's length, so to speak, only in water. On land, direct physical connections become essential. To survive on land, terrestrial organisms had to build for themselves structures and components that could perform the environmental services that marine organisms can take for granted."[35] Conduits and nodes of transfer of fluids were what life on land (or "hypersea") had to invent. Plant sap and animal blood have a direct evolutionary connection to seawater, they are new iterations, further developments of seawater itself. In this lineage, they not only carry the sea within them but further transform it: "living fluids are not a mere remnant or the analog of the sea; they are actually a new type of sea or marine environment: hypersea."[36] Hypersea signifies the oceanic milieu that nourished life, and what life had to learn how to actively self-maintain. In doing so, life on land transformed the sea itself. An aquatic milieu marks the beginning of all life, and perhaps it is the sea in its broadest sense that can ground a nonhuman approach towards gestation.

Water also lets one submerge, and if one dives deep enough, there is no longer light. Not only does life framed through light root the former in the stasis of death, it also implies that vision can help us understand both the origins and nature of life. In this project, I argue *against* the idea that a concept of light, and a philosophy best suited to study death, can bring about a philosophy that can embrace life. For Luce Irigaray, the question of birth—of where we come from—is of utmost concern. It is also impossible to ask in our current milieu as this question has been covered over by western philosophy. In her reading of Plato, the maternal provides the metaphorical and

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[35] Mark McMenamin and Dianna McMenamin, *Hypersea: Life on Land* (New York: Columbia University Press, 1994), 4.
[36] McMenamin and McMenamin, *Hypersea*, 25.

energetic means for a subject who is able to give birth to itself. Intimately connected to how light relies on the concept of vision as its grounding, Irigaray argues that life, when understood from the event of its birth, cannot be rooted in metaphors of vision. For Irigaray, the elevation of vision in the history of the West occurs through to a denigration of touch. Vision, by requiring some distance between subject and object, allows one to believe in autonomy. Touch not only is more primordial than vision; it also lines vision—it is vision's condition of emergence. The tactile informs and is always *felt* within vision. This is because the visual itself needs a more primordial sense of the touch as its origin: "vision [itself] is a mode of the tactile."[37] Irigaray suggests that the sense of touch offers a conception birth where the "sensible which is the feminine touches the sensible from which he or she emerges."[38] The tactile does not require light in its relation to life and surface, and instead, it is allied with darkness and depth.

Touch underscores and preconditions the senses of vision and hearing. For Irigaray, the metaphorics of touch extend to intrauterine life in a womb. Here, a dark fluid milieu is the condition for birth. It is tangible, fluid darkness that submerges life over and before light and vision. For Irigaray, what "is at stake in a metaphysics that wants to bring to light that which is not yet clear. And that maintains the most radical *polemos* with the maternal, the intrauterine: irreducible darkness."[39] The tangible and its concomitant darkness are the conditions of emergence for the other senses and the birth of the subject. Irigaray reminds us that before one sees light, one is already immersed and touched in a dark fluid milieu.

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[37] Irigaray, *An Ethics of Sexual Difference*, 175.
[38] Irigaray, *An Ethics of Sexual Difference*, 166.
[39] Irigaray, *An Ethics of Sexual Difference*, 171.

1.5 Beyond the Subject: The Logic of Fluids as the Logic of Life and A Subjectless Subjectivity

Thinking within and through water, a feminist philosophy of life must be wet. Life is not only submerged in water—it also necessitates we think through and with fluidity, because philosophies rooted in solid mechanics will not bring us towards a feminist philosophy of life. To think beyond "solid" mechanics entails a radical shift in how thought itself is grounded.

To start, a feminist philosophy of life cannot grant primacy to the subject; the "subject" cannot be its theoretical anchor. Privileging the subject instills and repeats a series of conceptual relations that, once again, are more adept at articulating a "dead" logic—a logic rooted in solids—the antithesis of a logic that can think life. According to Irigaray, the language we have inherited, our words are more "instrument[s] of death and not of life."[40] We are most adept at reducing beings to objects, and this tendency is especially ill suited to understand and grasp life. Despite this, Irigaray suggests that living beings themselves communicate what it means to be alive. Our language allows us to forget "our original experience of being in relations."[41] One never becomes alone, in a void without an *other*.

A feminist philosophy of life cannot operate through the subject, and for various reasons. In 1985, Donna Haraway famously declared that she would rather be a cyborg than a goddess.[42] Haraway pushed against a model of femininity mapped onto the Earth and the figure of a mother goddess who creates, arguing that these ideas, by relying on essentialist tropes, are regressive. Following Haraway, we can say that there is *no mother nature.* Nature cannot be understood as

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[40] Luce Irigaray, *To Be Born*: *Genesis of a New Human Being* (London: Palgrave Macmillan, 2017), 67.
[41] Irigaray, *To Be Born*, 67.
[42] Donna Haraway, *The Haraway Reader* (New York and London: Routledge, 2004), 39.

the body of a woman, or "female." One can argue that there is more than one reason for this. Nature is no more feminine than it is masculine and women are in no way "more natural" than men. I take up this idea and suggest that, if we think through the framework of nature born out Western science,[43] *nature cannot be understood through the idea of a Subject. Nature is not female*, not only because of this being essentialist, but also because a theory of the "Subject" does not undergird Nature. According to Elizabeth Grosz, focusing only on the subject repeats a tendency in feminist theory to think only about questions of identity:

> To the extent that feminist theory focuses on questions of the subject or identity, it leaves questions about the rest of existence—outside of and beyond or bigger than the subject, or what is beyond the subject's control—untouched. Feminism abdicates the right to speak about the real, about the world, about matter, about nature, and in exchange, cages itself in the reign of the ''I'': who am I, who recognizes me, what can I become? Ironically, this is a realm that is increasingly globally defined through the right to consumption, what the subject can have and own.[44]

To this I would add that not only does an exclusive focus on identity politics and theories of the subject occlude avenues of research regarding the rest of existence, but grappling with, and possibly producing a feminist philosophy of origins can never be invented through a theory of subject. This is a problem because I would argue the framework we have inherited and to which we are most habituated is a theory of a subject.

According to Irigaray, any theory of the subject has been appropriated by the masculine. When she asks if the subject of science is sexed, Irigaray is asking two things: 1) are the subjects—in other words, the questions and concerns—of science sexed, and 2) if the subject asking these questions has a particular sexed specificity (instead of being a "neutral" party) that

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[43] Indigenous cosmologies that figure a "Mother" nature are outside my purview here.
[44] Elizabeth Grosz, *Becoming Undone: Darwinian Reflections on Life, Politics, and Art* (Durham and London: Duke University Press, 2011), 84.

comes to directly inform the questions being asked. This question has wide-spanning ramifications, even if it may be something that science can ignore: "[b]ut the non-neutrality of the subject in the sciences makes itself heard in different ways—in particular, through what is discovered or not discovered at a given moment of history, and in what science does or does not take to be the stakes of its research."[45]

The concept of "subject" cannot be recuperated for an alternative philosophy or logic that does not elide and cover over feminine subjectivity. I would take Irigaray's point further and argue that not only is the notion of the "subject" irretrievable for feminist theory, we can extend and further transform this idea in a Nietzschean vein by giving up the idea of an *effective* subject him/itself, which would then free the object upon which effects are produced: "When one has grasped that the 'subject' is not something that creates effects, but only a fiction, much follows."[46] A theory of a subject necessitates an object upon which it acts, and mirrors a structuration of a cause that generates an effect. Not only is *any* theory of a "subject" not useful for developing here a feminist philosophy of life, it is particularly inept at theorizing the *origins* of cellular life.

Instead of a subject, perhaps the origins of life can be apprehended through the concept of *subjectivity,* particularly as it is conceptualized by French philosopher of science Raymond Ruyer. Such a subjectivity is "subjectless."[47] Ruyer argues that "[t]he subjectivity of an organic form (organic form as opposed to material and mechanical structure constructed by progressively linked liaisons) is subjectivity without a subject-individual who would be the proprietor of the

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[45] Luce Irigaray, "Is the Subject of Science Sexed?" *Cultural Critique* 1 (1985): 80-1.
[46] Friedrich Nietzsche, *The Will to Power*, trans. Walter Kauffman (New York: Vintage Books, 1968), 297.
[47] Paul Bains, "Subjectless Subjectivities," in *A Shock to Thought: Expression After Deleuze and Guatarri*, ed. Brian Massumi (London and New York: Routledge, 2002), 101-116.

consciousness."[48] Such a subjectivity is thoroughly non-anthropomorphic, and it precedes (and furthermore, conditions the possibility) a subject who is an "I." Such a "subjectivity" corresponds to a particular quality that marks all of life: a peculiar kind of unity that can endlessly differentiate. It is this further elaboration of subjectivity that I argue moves within a feminist philosophy of life.

In order to think with this idea of a subjectless subjectivity, a feminist philosophy of life would dissolve "the subject" by eradicating the logic that supports the subject: a logic of solids.[49] It would instead abide by a logic that is the logic of nature itself, rooted in and flows from fluid mechanics. The language of the subject is rooted in, made possible by, a certain formulation of logic, one that not only separates subject and object, but that also operates through freezing reality, one molded on the logic of solids (and by extension, a rigid sense of being)—all of which is incapable of attuning itself to the study of life. Irigaray posits that the "problem of the sexuation of discourse has, paradoxically, never been posed."[50] In so doing, as the subject of this discourse, Man becomes a sole subject that exists. This then makes *his* particular epistemic structure, his language (*langue*) "appear to be the universal itself."[51] Irigaray argues that the establishment of *langue* begins from one perspective that becomes invisible by being given status as the universal; her bringing this philosophical and political maneuver to our attention "shakes the foundations of what was given as universal."[52] If the particular viewpoint and perspective of

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[48] Raymond Ruyer, "There is No Subconscious," *Diogenes* 36, no. 142 (1988): 29.
[49] It should be noted that I am *not* collapsing this subjectless subjectivity that encompasses organic form with a logic of fluids. Both move us away from the "subject" and its allied logic of solids, but in different ways. They are not the same, but together are crucial for a feminist philosophy of life.
[50] Luce Irigaray, "The Language of Man," *Cultural Critique* 13 (1989): 191.
[51] Irigaray, "The Language of Man," 191.
[52] Irigaray, "The Language of Man," 192.

one subject has become the universal, an interrogation of the sexuation of discourse cannot simply be a local interrogation. She argues:

> In the pre-Socratics, we still find the exorcism-or at least the framing-of fluids by solid realities: the world-*cosmos* surrounds itself with a shell in Empedocles, the world-thought closes itself up in a circle with Parmenides. Western logic calls for and relies on a mechanics of solids. The fluid will always spill over reason, ratio, go beyond measure, plunge back into the undifferentiated: a universe of myths and magic, a night resisting the lucidity of the philosophers who will only approach it to re-enclose it within the shores of their thought. Forgetting that, without fluidity, their thought would have no possible unity, that fluid always subsists between solid substances to join them, to re-unite them. Without the intervention of fluids, no discourse would hold together. But the operation of fluids doesn't state itself as a condition of truth, of the coherence of the logos. To do that would be to reveal the instability of its edifice, the moving ground beneath it. Don't the sciences interpret, in their own manner, the fulfillment of philosophy as the end of the prevalence of a logic of solids? Aren't they discovering or rediscovering the properties of a dynamic of flow that discourse still resists, constraining us to obey a world of outdated reason, even though we actually live in a universe where the power of fluids is becoming more and more dominant?[53]

Irigaray draws attention to fluids because they embody an alternative window on how to conceive of reality, and consequently another way to do practice logic. The properties of fluids that the sciences are (re)discovering exemplify that fluids correspond with the real; solids are "cut" from fluids—a solid is a statisticized block of what was once first fluid. A fluid logic aligns with feminine subjectivity, as well as the reality of nature, what we could call the *real* real. A logic at work in a feminist philosophy of life would be an expression of such a fluid logic.[54]

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[53] Luce Irigaray, "The Language of Man," 199-200.

[54] This idea can be further specified through a quick foray into fluid mechanics. In physical terms, a solid is a material whose "constituent elements" resist changing shape when an external force is applied. Solids strongly retain their form. In contrast, a fluid thus readily deforms to a large degree when an external force is applied. "The defining property of fluids, embracing both liquids and gases, lies in the ease with which they may be deformed so much so that we can say that that the defining feature of fluidity is "easy deformability" (G.K. Batchelor, *An Introduction to Fluid Dynamics* (Cambridge: Cambridge University Press, 2000), 1-2). Fluid statics (the study of fluids at rest) together with fluid dynamics (the study of the *flow* of liquids and gases) make up the discipline of fluid mechanics. Water may most immediately come to mind when one thinks of fluid, but *air* is a "fluid" as well in fluid dynamics. Though outside the scope of this current

This alternative logic would not organize itself around the privileging of the "One."[55] She writes, "The Dominion of the One, of the sameness of the One, in Western logic, supports itself on a binarism that is never radically called into question."[56] A logic of *at least two* would challenge the primacy and privileging of the principles of self-identity and non-contradiction (two of the three major tenets of Aristotelian logic).[57] This binary logic, according to two Irigarayan scholars,

> is sufficient for death of the body but not for life or the living flow of ideas. The rigidity of a corpse can be described without allowing for growth and change, but a living body cannot. Conception, gestation and birth all depend on fluids; just as living creative thought and becoming require fluidity and movement, not binary principles...In that living body, nothing and no one can be fitted exactly. Whole without parts. Indefinitely mobile. Impulse, change, the process of becoming, these cannot be imposed from the outside, from something considered as a law or principle.[58]

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project, it should be noted that an Irigarayan engagement with fluid dynamics should also address not only liquid, but also air. This echoes Hill's argument that "[a]long with sexual difference, Irigaray argues that air is necessary for life on Earth. I agree with Irigaray's affirmation of the air, provided that her inscription of "air" is read loosely to include the various habitats of the oceans, earth and gases that make up this planet and the environs of the planet. I do think that her concept of air is worth complicating to take more specific account of the various milieus of the Earth and the cosmos" (Rebecca Hill, "Milieus and Sexual Difference," *The Journal of the British Society for Phenomenology* 45, no. 3 (2014): 230).

[55] Irigaray challenges the logic of the One, which insists and relies on a repetition of the same. Taking up the question of the one and many, she asks, "What if women were always 'at least two,' without any opposition between those two, without reduction of the other to the one, without any possible appropriation into a logic of the one, without an autologic closure of the circle of the same? Always at least two, which never boil down to a binary alternative: the logic of distancing and of the mastery of the other? What is they always spoke *many* at a time, without the many being reducible to the multiple of one? How would truth assimilate into its economy this enigmatic speech (*parole*), without any known principle of self-identity, or of non-contradiction? What would become of the universal that lays down the law?" (Irigaray, "The Language of Man," 197-8.).

[56] Irigaray, "The Language of Man," 196.

[57] Irigaray, "The Language of Man," 196.

[58] Hanneke Canters and Grace M. Jantzen, *Forever Fluid: A Reading of Luce Irigaray's Elemental Passions* (Manchester: Manchester University Press, 2005), 153.

The idea that Nature is at least two moves us towards an altogether different logic, one that would be a logic of contiguity that generates difference in itself rather than through oppositions.[59] Instead of a principle of contradiction that focuses on the mutual exclusiveness between two terms, Irigaray cultivates a logic of difference, one that is fundamentally fluid, and therefore at odds with the principle of identity and the principle of non-contradiction. An Irigarayan logic would not be seized and solidified by the category of identity—it would never aim to remain one single thing, and thus would be the opposite of an "essentialist" reading.[60]

Instead of self-identity, Irigaray offers us the concept of *relational* identity, which does not root itself in the identity to the same. She writes:

> [Self-identity] designates a reality which is if possible fixed, not subject to change, not modifiable by the event nor by the other. In this way it has something in common with the Platonic idea. Relational identity goes counter to this solipsistic, neuter, auto-logical ideal. It contests the cleavages sensible/intelligible, concrete/abstract, matter/form, living/dead. It also refuses the opposition between being and becoming, and the fact that the plural of the one would be the multiple *before* being the two. Relational identity considers the concrete identity which is always identity in relation. As such, it is always metastable, becoming."[61]

Relation here cannot be thought as simply a spatial extension of the same. It also does not refer to a connection or an imaginary line between two static entities. It is instead much more capacious and generative. Irigaray's aim in crafting a logic of relational identity is to be able to articulate a concept that is attuned to "the constant transformation required by a living connection to nature"

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[59] Rachel Jones, *Irigaray*: *Towards a Sexuate Philosophy* (Malden, MA and Cambridge: Polity Press, 2011), 85.
[60] Irigaray is often (mis)understood as an essentialist who solidifies the category of "woman" in her writings. This has been the source of intense debates within feminist theory. See Naomi Schor, "This Essentialism Which is Not One: Coming to Grips with Irigaray," *differences* 2 (1989): 38-58, as well as Pheng Cheah and Elizabeth Grosz, "The Future of Sexual Difference: An Interview with Judith Butler and Drucilla Cornell," *Diacritics* 28, no. 1 (1998): 19-41.
[61] Luce Irigaray, *Conversations* (New York and London: Continuum, 2008), 12, emphasis added.

and a self that is always in the process of becoming. This formulation of identity is not about the preservation and solidification of a particular concept (or subject); it instead *addresses both* being and becoming. This logic of metastability is much more robust and "alive" than the logic of self-identity. Because of this, and as Irigaray herself notes, it brings forward the possibility of *contesting* the binaries that we have used to cleave the world as well as our thinking. "The living," for Irigaray, "is that which continues to grow, to become."[62] Moreover, this growth is never simply an increase of the same, but, at the same time, the new is not ushered in a way that would destroy what currently exists. A living being continues to become by carefully and endlessly modulating itself. It invents new ways to live, but in a manner that does not exterminate itself (because to do so would mean it would cease to live). A relational identity would be able to address this interrelation between being and becoming that life situates itself within.

1.6 Feminism and Biology

Though this project closely reads and meditates on scientific research, its method of engagement differs from more traditional methods of feminist engagements with science. The earliest works on feminism and biology, and feminist science studies more broadly, focus on how problematic concepts of gender implicitly and explicitly inhere in scientific research.[63] Here, the aim is to identify, critique, and subsequently eliminate "gender bias" within research. Feminist

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[62] Irigaray, *Conversations*, 12.

[63] See, for example, Ruth Hubbard and Mary S. Henefin, eds., *Woman Looking at Women Look at Biology* (G K Hall & Co: Boston, 1979); Ruth Hubbard, Mary Sue Henifin and Barbara Fried, eds. *Biological woman, the convenient myth: a collection of feminist essays and a comprehensive bibliography* (Schenkman: Rochester, VT, 1982); Ruth Bleier, *Science and Gender: A critique of biology and its theories on women* (Elmsford, New York: Pergamon,1984); Ruth Hubbard, *The Politics of Women's Biology* (New Brunswick and London: Rutgers University Press, 1990); and Sue V. Rossler, *Feminism and Biology: A Dynamic Interaction* (New York: Twayne Publishers, 1992).

philosopher of science Lynne Hankinson Nelson argues that "feminist scientists and science scholars claim to have shown that many disciplines, including many sciences, have relied on, and in many cases, continue to rely on, unquestioned, unwarranted, and, at times also unrecognized, assumptions about gender."[64] Rooted in sociocultural conceptions of "male" and "female," feminist scholars of science have argued that the evocation of "female" does not begin with science directly focused on humans or animals. "Gender bias" is at play even at the level of the microscopic. In her study of gender bias in the field of molecular biology, Bonnie Spanier argues that the gendered language within this field is less direct but no less problematic. Science, it seems, cannot but use the contemporary patriarchal idea of gender as an implicit source to generate research:

> When the subject matter is less obviously gendered, as in chemistry, physics, or molecular biology, the descriptive language becomes less explicit in gender symbolism. Feminist theory proposes that language focusing on domination, hierarchical control, and polar dichotomies both reflects and condones masculine ideology. Indeed, such beliefs are embedded in studies of life at the microscopic level.[65]

Feminist scholars have demonstrated when gender is brought to bear on a cellular level, "masculine" and "feminine" parts of the cell, such as nucleus and the cytoplasm, or, alternatively, the egg and the sperm, operate through dichotomies of activity and passivity, respectively. One solution to this that the Biology and Gender Study Group, a coalition of feminist scientists, offer is that in order to "make biology a better discipline," the rampant gender bias within biology must be "controlled" in scientific discourse.[66] In more recent scholarship, the question of how to

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[64] Lynn Hankinson Nelson, *Biology and Feminism: A Philosophical Introduction* (Cambridge and New York: Cambridge University Press, 2017) 1-2.
[65] Bonnie Spanier, "Gender and Ideology in Science: A Study of Molecular Biology," *NWSA Journal*Vol. 3, No. 2 (Spring, 1991): 167-198; 177.
[66] The Biology and Gender Study Group, "The Importance of Feminist Critique for Contemporary Cell Biology," *Hypatia* 3, no. 1 (Spring 1988): 73. See also Emily Martin, "The

conduct science that is without bias has shifted to a focus on how feminist bench science might be undertaken.

Deboleena Roy's *Molecular Feminisms: Biology, Becomings, and Life in the Lab* extends the question of feminist biology by transforming the question of finding bias to producing research informed by feminist inquiry. Roy seeks to develop a more recent feminist engagement with biology, specifically molecular biology. Using a Deleuzian-inspired approach, Roy's aim is not to undertake a "molar" approach to feminism and science that focuses its attention on questions of pre-given identity and stasis. Instead, she seeks to reframe the relation between molecular biology and feminism by crafting a kind of "molecular feminism"—one that thinks through becoming and a Deleuzian microphysiology of desire in order to demonstrate how biology is neither essentializing or deterministic.[67] Roy speaks to both a women's studies audience and scientists (or, more precisely, to "feminist scientists" and "scientist feminists") interested in incorporating the insights of feminism into their empirical research. She suggests that the rise of feminist new materialism's interest in matter and our more-than-human world can be pushed further by conducting new scientific research (in addition to shifting the subject of study). On this, Roy notes:

> Although new ontological gestures have revived feminist theory's engagements with the sciences and with biology in particular, without an effort to connect this theory to the theory and practices taking place at the level of the lab bench, these gestures run the risk of suffering a similar fate as that of poststructuralist feminist theory and earlier feminist critiques of science, which rightly or wrongly have been accused of working to restrict our access to the natural world.[68]

Egg and the Sperm: How Science Has Constructed a Romance Based on Stereotypical Male Female Roles," *Signs*, 16, no. 3 (1991): 485-501.

[67] Deboleena Roy, *Molecular Feminisms: Biology, Becomings, and Life in the Lab* (Seattle: University of Washington Press, 2018), 5.

[68] Roy, *Molecular Feminisms*, 12.

Roy's aim is to galvanize novel ways to incorporate insights from feminist theory and biophilosophy (which she distinguishes from philosophy of science) into the practice of bench science itself. She particularly uses Deleuze and Guattari's writings, as well as Deleuzian-inspired feminisms,[69] to gesture towards a different way to practice science.

Roy's experimental approach to what could be a feminist laboratory is important for current scientists. Though this exemplifies a general trend beginning to ripple across feminist science studies more broadly, my approach in this project differs from this task. My aim in this project is not to gesture toward a laboratory politics (though that is an important task). I am not suggesting an alternative method for practicing science within the lab. Rather, I am interested in how conceptual shifts that are occurring in origins research may align themselves with a feminist philosophy of life. This project is not a "neutral" representation of origins of life research. It instead focuses on particular strands of origins research, ones that reimagine matter and life in novel ways, and thus can have potential implications for a feminist philosophy of life. How do central concepts within feminist theory—such as what has been historically, philosophically, and culturally marked as "feminine" or "maternal"—live and operate within contemporary origins research? Given how origins research ultimately concerns the question of beginnings, I am interested in how such work allies with feminist inquiry. If one of the central aims of origins research is tell us where we come from, this project experiments with how feminist concepts can develop an ontology using science.

According to feminist theorist Elizabeth Wilson, feminist engagements with science have functioned in a way that excludes a direct engagement with science itself. For Wilson, despite the feminist turn to "body" undertaken in the late 1980s and throughout the 1990s, a direct

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[69] Roy particularly relies on Braidotti and Grosz.

engagement with biological research concerning the body is lacking.[70] Often times feminist engagements with the body take up the question of how the body is discursively represented more so than an engagement with its corporeal, fleshy, and biological nature.[71] Wilson argues that the seismic effects of Judith Butler's influential reformulation of gender forecloses the possibility of a feminist engagement with biology. For Wilson, "gender theory" has had such a large effect on feminist studies that the sex/gender binary has now become the gender/sex binary. In this reformulation, the performative constitution and iteration of gender negates the possibility to understand or grapple with sex. Sex—the fleshiness of the biological—itself disappears. In this schema, a feminist engagement with "biology" becomes near impossible. In the sex/gender distinction, "biology becomes the excluded, unthought, simple ground from which feminist analysis is fashioned."[72] This is particularly problematic for a feminist engagement with biology because the intelligible matrix of gender "cannot generate, accommodate, or sustain" a direct engagement with biology. [73] For Wilson, feminist theory's inability to engage the biological generates a paradox: "antibiologism both places conceptual limitations on feminist theory *and* has been one of the means by which feminist theory has prospered."[74] This project takes Wilson's warning seriously, and directly grapples with the material and physical forces that constitute

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[70] Works such as Linda Birke's *Feminism and the Biological Body* are more about the biological representation of the body and its associated metaphors rather than biology itself (Edinburgh: Edinburgh University Press, 1999).
[71] See, for example, Susan Rubin Suleiman, *The Female Body in Western Culture: Contemporary Perspectives* (Cambridge, MA: Harvard University Press, 1986), Janet Price and Margrit Shildrick eds., *Feminism Theory and The Body: A Reader* (New York: Routledge, 1999) and Susan Bordo, *Unbearable Weight: Feminism, Western Culture, and the Body* (Berkeley and Los Angeles: University of California Press, 1993).
[72] Elizabeth Wilson, *Neural Geographies: Feminism and the Microstructure of Cognition* (London and New York: Routledge), 55.
[73] Wilson, *Neural Geographies*, 62.
[74] Elizabeth Wilson*, Gut Feminism* (Durham and London: Duke University Press, 2015), 4.

biology. It is less interested in how the biological body is represented, and directs its attention to how a careful scrutiny of scientific research on the origins of life generates a feminist philosophy of life that teases out the ontological implications of such research.

1.7 The Limits of Symbiosis, The Biology of Number, and Horizontal Gene Transfer

In order to continue to flesh out my method and the central questions and concepts of this project, it is helpful to point out general ways biology, particularly evolution, has been taken up by critical and feminist thought in the humanities. The idea that biological evolution is fundamentally about the linear genealogy of atomic individualism has been critiqued both within the humanities and much of the sciences. Evolutionary theory rooted in the "tree of life" is not just a metaphor but a literalized framework in research.[75] As Deleuze and Guatarri suggest, an arboreal theory of evolution creates the fantasy of a vertical genealogy as the most prevalent force of biological life.[76] According to anthropologist of science Stefan Helmreich, "lateral gene transfer in microbes places in jeopardy the vertical inheritance needed to root the tree of life."[77] As one scientist puts it, "there is no such thing as a tree of life. The idea of a tree of life, which stringently follows Darwin[ian] theory, is not pertinent in the genomic age…we know that current organisms are chimeric, and made up of a mosaic of sequences of different origins that makes…the tree look more like a forest."[78] This is to say that evolutionary biology, or biology as

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[75] See, for example, contemporary articles such as Moreira and Lōpez-Garcia, "Ten reasons to exclude viruses from the tree of life," *Nature Reviews Microbiology* 7 (2009): R306–R311
[76] Deleuze and Guattari, *A Thousand Plateaus*: *Capitalism and Schizophrenia*, trans. Brian Massumi (Minneapolis: University of Minnesota Press, [1980] 1987), 237-9.
[77] Stefan Helmreich, *Alien Ocean: Anthropological Voyages in Microbial* Seas (Berkeley: University of California Press, 2009), 87.
[78] Didier Raoult, "There is no such thing as a tree of life (and of course viruses are out!)," *Nature Reviews Microbiology* 7 (2009): 615.

a modern science more broadly, realizes that one of its founding arborescent metaphors does not attend to the reality of biological life. The microscopic world makes this abundantly clear. Horizontal gene transfer—the immense trading of genes in the microscopic world that bacteria and viruses partake in—challenges the idea that evolution is principally about linear arborescent genealogy.[79] In lieu of a tree, scientists suggest there is more of a *web* of life.[80]

In this project, I also seek to displace the centrality of the linearity of evolution. As someone who has been interested in the microscopic world ever since I studied microbiology, I fully concur that the importance of horizontal gene transfer cannot be understated. Though evolution is just as much if not more horizontal than it is generational, this does not in itself answer the question of how life begins**.** Horizontal gene transfer operated in the earliest time period of cellular (and even pre-cellular) life, but it cannot replace the scientific and philosophical question of *origins* itself. In other words, the question of where life comes from still is necessary to ask even if we decenter the centrality of a vertical genealogy (the latter of which aligns with the desire to both produce and trace a patriarchal lineage).

Another recurring theme in feminist engagements with biology is the displacement of the centrality of the human in the natural world, which is accomplished by calling attention to the sheer *numbers* of nonhuman living agents that compose the human and its exterior milieu. In the realm of the biological, what is organically human quantitatively pales in comparison to the living entities within and outside its bodily boundaries. Take, for example, what Donna Haraway writes in *When Species Meet*:

> I love the fact that human genomes can be found in only about 10 percent of all the cells that occupy the mundane space I call my body; the other 90 percent of the cells are filled

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[79] The importance of lateral gene transfer directly connects to, and strengthens the contemporary desire to biogenetically bank as many life forms as possible.
[80] Luis Villarreal, "Are Viruses Alive?" *Scientific American* August 8 2008

> with the genomes of bacteria, fungi, protists, and such, some of which play in a symphony necessary to my being alive at all, and some of which are hitching a ride and doing the rest of me, of us, no harm. I am vastly outnumbered by my tiny companions; better put, I become an adult human being in company with these tiny messmates. To be one is always to become with many.[81]

The human body here becomes a community in which human genomes are outnumbered by microscopic genomes that live within and on the human body. While some of these agents simply exist in our inner and outer environments, others actively shape our health. Haraway demonstrates how companion species such as humans and dogs co-evolve in a milieu together and how their species-stories are intertwined. To live is to always become-with a multiplicity of beings that are nonhuman.

In a similar vein, feminist scholar Myra J. Hird utilizes the sheer number of bacteria that shape what it means to be human body to argue that human, as an identity, is itself is bacterial:

> Symbionts all the way down as I have called it, encapsulates our bacterial identities. The web or ring of life is both made possible by and entangled with bacteria. Through deep time we are more than connected to bacteria. We are kin through symbiogenetic mergers. Human bodies are symbionts: 600 kinds of bacteria in our mouths and 400 kinds of bacteria in our guts, and the countless more bacteria that inhabit our orifices and skin. Indeed, the number of bacteria in our mouths is comparable to the total number of human beings that have *ever lived* on earth. The number of microbes in our bodies exceeds the number of cells in our bodies by 100 fold…Every living thing that exists now, or has ever lived, is bacteria. Asking what bacteria have to do with humans is…asking the wrong question…"[82]

The sheer number of bacteria that constitute the bodily space referred to as human, "challenges the very notion that there is an outside to ourselves: a symbiogenetic heritage means environments are incorporated and become ourselves at genetic, morphological, physiological,

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[81] Donna Haraway, *When Species Meet* (Minneapolis: University of Minneapolis Press, 2007), 4.
[82] Myra J. Hird, "Animal, All Too Animal: *Blood Music* and an Ethic of Vulnerability," in *Animals and the Human Imagination: A Companion to Animal Studies*, ed. Aaron Gross and Anne Valley (New York: Columbia University Press, 2012), 338.

and developmental levels."[83] Haraway and Hird push us to reconsider the human body's political and ontological centrality given how a more-than-human population constitutes core bodily systems of the human body such as digestion and thinking.

The decentering of the Human through the sheer number of nonhumans that constitute its being is a technique that critiques the notion of the "individual" as the basis of science. Indeed, this reframing calls into question the major tenets of the life sciences that have dominated thought the twentieth century. On this Haraway writes,

> What happens when human exceptionalism and bounded individualism, those old saws of Western philosophy and political economics, become unthinkable in the best sciences, whether natural or social? Seriously unthinkable: not available to think with...What happens when the best biologies of the twenty-first century cannot do their job with bounded individuals plus contexts, when organisms plus environments, or genes plus whatever they need, no longer sustain the overflowing richness of biological knowledges, if they ever did? What happens when organisms plus environments can hardly be remembered for the same reasons that even Western-indebted people can no longer figure themselves as individuals and societies of individuals in human-only histories?[84]

Haraway notes how this powerfully becomes the case with multicellular life, where instead of the self-making paradigm of *autopoiesis,* there is always an sym*poeisis*, a "making with." Making with, rather than self-making, finds its origins in symbiogentic thinking. First formulated by Russian biologist Konstantin Mereschkowski in the early twentieth century,[85] but popularized by Lynn Margulis, symbiogenesis is a theory about the origins of eukaryotic cells, or "complex" cellular life that possesses a membrane-bound nucleus and organelles. It argues that eukaryotes

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[83] Hird, "Animal, All Too Animal," 344.
[84] Haraway, *Staying With The Trouble: Making Kin in the Chthulucene* (Durham and London: Duke University Press, 2016), 30.
[85] See Jan Sapp, Francisco Carrapiço and Mikhail Zolotonosov, "Symbiogenesis: The Hidden Face of Constantin Merezhkowsky," *History and Philosophy of the Life Sciences* 24, no. 3/4 (2002): 413-440.

arose from an ancient symbiotic merger between an archaeal and bacterial cell.[86] Through her groundbreaking research, Margulis argues that the origin of eukaryotic cells resulted from ancient symbiotic mergers of larger prokaryotic cells (which *lack* a distinct nucleus and membrane-bound organelles) engulfing smaller prokaryotic cells but *not* killing these now trapped cells. The smaller "eaten" or "engulfed" prokaryotes, still alive but no longer free-living, became the organelles one finds in eukaryotic cells. Feminist theorists, as well as science studies scholars more generally, have taken up symbiogenetic thinking to debunk the concept of an autonomous, singular "individual." A time slice of any modern biological individual—whether a single-celled algae or the ecosystem inside an animal—demonstrates that an individual is never "one." Symbiogenesis powerfully reminds us that an "individual" is always a multiplicity. Through symbiogenetic thinking, we learn that evolution is propelled by lateral events as much as it is transformed by vertical genealogical filiation.

Though symbiosis has decentered the individual in biology, like the emphasis of sheer number, it alone cannot generate a theory of how life begins. There must be "beings" already in existence for them to symbiotically interact and become-with. How are the subjects that are incorporated into one another themselves produced? Life is indeed further complicated through symbiosis, but what makes symbiosis itself possible? What needs to first emerge for something like horizontal gene transfer to shuffle and fundamentally reorder the web of life?

The power of symbiogenetic theory is that it critiques the idea of individualism while its shortcoming is that it fails to provide a theory of ontogenesis. In other words, symbiosis cannot address what can be understood as the study of developmental biology in its broadest sense: the

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[86] Lynn Sagan, "On the Origin of Mitosing Cells," *Journal of Theoretical Biology* 14 (1967): 225–274.

question of the origins of ontogenesis and biological form. How does life come into being? In an earlier work, I argued that symbiosis, when understood from a viral perspective, complicates the living/nonliving distinction and makes even the prokaryotic single cell a viral symbiotic invention. I decentered Margulis' focus on more complex forms of cellular life (eukaryotes, which are the results of an ancient symbiotic merger) through a viral reading.[87] This approach does bring us further back in life's evolutionary beings, but even here the question of what we could call developmental biology—of how life comes or forms itself into being—is not addressed. A logic of contagion does run across life, but such a logic still has as its ground an unnamed (and non-theorized) ontogenesis. A completely different orientation is needed to theorize in the "gap" between what we understand as chemistry and the beginnings of cellular life.

While the theoretical consequences of Margulis' thought have been explored,[88] there is a lack of recognition in critical theory, however, that her research *only* explains the shift in the evolution of life from single-cell prokaryotic life to more complex and differentiated eukaryotic life. If one begins with an already functioning and evolved single-celled organism, the problem of the *emergence of life from matter* has already been solved. Instead one must think further back in time to theorize the emergence of the first membrane-bounded cell. This is a different scientific question than symbiogenesis and therefore requires its own theoretical foundation. If modern

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[87] See Annu Dahiya, "Before the Cell, there was Virus: Rethinking the Concept of Parasite and Contagion through Contemporary Research in Evolutionary Virology," in *Transforming Contagion: Anxieties, Modalities, Possibilities,* Breanne Fahs, Annika Mann, Eric Swank, and Sarah Stage, eds., (New Brunswick, NJ: Rutgers University Press, 2018), 42-55.
[88] See, for example, Myra J. Hyrd's *Sex, Gender, and Science* (New York: Palgrave Macmillon, 2004) and *The Origins of Sociable Life: Evolution After Science Studies* (New York: Palgrave Macmillon, 2009).

biology regards the cell as the minimal unit of life, solely focusing on the evolution of eukaryotic cells from prokaryotic cells does *not* posit the origins of cellular life itself.

It is only the study of the relation between matter and life—of how the physical and chemical condition the possibility of the biological—that can ground a feminist philosophy of life set on studying the emergence of cellular life. Such an investigation would mark the condition of possibility of symbiosis itself. By theorizing the origin of cellular life *itself*, this dissertation addresses a gap in feminist theoretical scholarship regarding how life emerged from its material environments.

In addition to thinking *before* and *beyond* symbiogenesis, this dissertation addresses the emergence of life without foregrounding genetics at and as its conceptual center. Genetics, especially in our present, always has a tendency toward making life into property by freezing life forms in genetic databases that one then can own. This ability to own biological life (a desire that does not begin with biotechnological advancements of the 1970s) in the sense of patents is possible if one slightly modifies an "indigenous" life form, which cannot outright be owned. The more we understand life as genetic, the more it becomes informatic, the more it is something that can be owned. Indeed *metagenomics* is a contemporary subfield of genetics whose main aim is to scan and digitally bank the genomes of all environments, from the terrestrial surface of the Earth to the deep-seas. When a genome from an environment is scanned and does not have a match in a database, a new organism (or bits of an organism) is declared to have been discovered. Though metagenomics is rapidly expanding our understanding of the diversity of life, this increase in our knowledge of biological diversity cannot be separated from the desire to use, manipulate, control, and profit from the new biological lifeforms that are "discovered." Thus the first reason I eschew crafting a feminist philosophy of life's cellular origins from a genetic frame is because such a perspective risks atomizing identity (that is presumed to be found or "located" within a genetic

sequence). The second reason I displace the centrality of genetics in this project is because I do not believe that the most primordial events of life's eruption from matter began with genetics. I spotlight origins research that argues genetics is an effect of more primordial forces of becoming.

1.8 Life from Matter: From Spontaneous Generation to The Origins of Life

The debates surrounding spontaneous generation are crucial historical precursors to origins research that begins in the mid-twentieth century.[89] The relation between matter and life—specifically the latter's emergence from matter—has been theorized in terms of "spontaneous generation" for almost two millennia, from Ancient Greece to the nineteenth century. Aristotle understood a wide array of animals, such as fish, eels, plants, and insects, and testacea, to spontaneously generate. Spontaneously generated animals arose by chance through non-reproductive means and thus differed from animals born out of sexual generation, the latter teleologically and purposefully developing towards a final cause.

Historian of science John Farley notes that spontaneous generation undergoes a significant shift over the course of the seventeenth century following the rise of Cartesianism. In the beginning of the century, spontaneous generation could be explained by the doctrine of mechanistic philosophy through principles of matter and motion. For Descartes, that matter and motion could account for the generation of an animal and generation was an expression of the universal laws of nature.[90] In the Cartesian inflection of spontaneous generation,

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[89] An in-depth account of the spontaneous generation debate is found in John Farley, *The Spontaneous Generation Controversy from Descartes to Oparin* (Baltimore and London: The Johns Hopkin University Press, 1974). See also Iris Fry, *The Emergence of Life on Earth: A Historical and Scientific Overview* (New Brunswick: Rutgers University Press, 2000), 9-53.
[90] Farley, *The Spontaneous Generation Controversy from Descartes to Oparin* (Baltimore and London: The Johns Hopkins University Press, 1974), 8.

> ...it was merely necessary for heat, acting on putrefying matter, to agitate the subtle and more dense particles to form an organic being. Similarly, sexual generation and embryological development were seen in terms of matter and motion: 'If one knows well what are all the parts of the seed in a certain species of animal, for example of man, one could deduce from that alone, by reasons entirely mathematical and certain, the whole figure and conformation of each of its members.'[91]

By the mid and late seventeenth century, the Cartesian idea that matter and motion alone can account for animal generation was called into question. The complexity of animal and sexual generation was directly at odds with a Cartesian conception of nature. The question of chance, which under laid the idea of spontaneous generation, threatened Cartesian nature due to its deviation from a knowable, predictable future. Farley suggests that this desire to subdue chance and to have a predictable future led to a theory of germ pre-existence. Different from preformation (which is the idea that germ is a "mere mechanical growth of a miniature [being] preformed *in the parent organism*"), preexistence encompassed the idea that "the germ of preformed part is not produced by the parent, rather it is created by God at the beginning and is conserved in that state until the moment of its development or *l'evolution*."[92] Preexistence was used as a defense against the atheism that spontaneous generation suggested.

In the same time period, Italian biologist Francesco Redi (1626-1697) destabilized the idea of spontaneous generation through what is now regarded as a classic experiment in the history of microbiology. Redi devised an experiment to test what was then the widespread belief that maggots spontaneously generated from rotting meat. This experiment consisted of placing meat in a series of flasks. With some flasks, he sealed them completely to the outside, while with others, he partially covered the flask opening with gauze. Redi also kept some flasks open to the

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[91] Farley, *The Spontaneous Generation Controversy*, 8, citing René Descartes, 'Formation de l'animal' in *Oeuvres*, ed. Ch. Adam and P. Tannery, 12 vols. (Paris, 1897-1913), 11: 277.
[92] Farley, *The Spontaneous Generation Controversy*, 12.

air with no covering of any kind, which functioned as a kind of control experiment.[93] After several days, the control resulted in the appearance of maggots and subsequently flies directly on the meat, while the sealed flask had no spontaneous generation of flies, and the flasks covered with gauze had maggots on top of the gauze but not internally within the flask on top of the meat. While spontaneous generation and abiogenesis (scientific theories of how life emerged from matter) share the idea that there *is* a relationship between "not living" matter and "living matter," a major difference between the two ideas that the former has no idea of time—specifically, a kind of long evolutionary time—in its formulation. Like the maggots that arise out of meat, within the realm of spontaneous generation, life arises from nonliving matter on a daily basis. Despite Redi's experimental proof that spontaneous generation cannot occur, his research did not put this debate to rest.

An even more well-known opponent of spontaneous generation than Redi is the scientific giant Louis Pasteur (1882-1895). Pasteur devised an experiment where beef broth was boiled and sterilized in swan-neck flasks. The architecture of these flasks allowed for sterilized beef broth to be sealed off from the surrounding air. If the broth was kept sealed off from the air, the broth remained free from microbial contamination. It was only when the broth was exposed to air that "spontaneous generation" occurred. Pasteur effectively ended the debate of how life arises from matter for the rest of the nineteenth century. For Pasteur, the air is germinal with "life itself." Pasteur's experiments demonstrated how nonlife *cannot* generate life. *Omnis cellula e cellula*: all

[93] Because he incorporated a flask which had meat fully exposed to the air, Redi is cited as developing the first experiment that used a control factor.

cells come from cells.[94] Biogenesis prevailed. By demonstrating that life must come from life, however, Pasteur's success made the question of origins almost impossible to ask.

Debates regarding spontaneous generation in the nineteenth century sat uneasy with theories concerning the evolution of life, especially theories of life's origins. In a letter to his close friend Joseph Dalton Hooker in 1871, Charles Darwin speculated on the possibility of life's origin:

> It is often said that all the conditions for the first production of a living organism are now present, which could ever have been present.— But if (& oh what a big if) we could conceive in some warm little pond with all sorts of ammonia & phosphoric salts,—light, heat, electricity present, that a protein compound was chemically formed, ready to undergo still more complex changes, at the present day such matter w[ould] be instantly devoured, or absorbed, which would not have been the case before living creatures were formed.[95]

Since its initial printing in 1859, the question of the "origin" of life in *The Origin of Species* is absent. This is a well-noted absence. In a letter to Dalton eight years later in 1863, Darwin thought that "...it is mere rubbish thinking, at present, of origin of life; one might as well think of origin of matter."[96] Though never publicly writing on the origin of life, Darwin's interest in the possibility that life arose in some way from matter (privately) captured his interest. The question

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[94] This idea was first put forth by German biologist Rudolf Virchow in *Cellular Pathology* (1858). Virchow writes, "Where a cell arises, there a cell must have previously existed (*omni cellula e cellua*), just as an animal can spring only from an animal, a plant from a plant...in the whole series of living things, whether they be entire plants or animal organisms, or essential constituents of the same, an eternal law of *continuous development* prevails. There is no discontinuity of development of a such kind that a new generation can of itself give rise to a new series of developmental forms" (Virchow, *Cellular Pathology* (London: John Churchill: 1978), 27-8.

[95] Darwin Correspondence Project, "Letter no. 7471," accessed on 23 September 2017, http://www.darwinproject.ac.uk/DCP-LETT-7471. Also published in *The Correspondence of Charles Darwin*, vol. 19

[96] Darwin Correspondence Project, "Letter no. 4065," accessed on 23 September 2017, http://www.darwinproject.ac.uk/DCP-LETT-4065. Also published in *The Correspondence of Charles Darwin*, vol. 11.

of spontaneous generation was an intense intellectual and theological controversy in the nineteenth century. The idea of there being a *bridgeable* gap between matter and life was potentially heretical at this moment.

Despite Darwin's reluctance to theorize on the origins of life, the idea of evolution that he develops—the idea that living beings move from simple to complex—is part of a larger intellectual and scientific shift in the nineteenth century where the fixed stability of the universe, and with it living beings, becomes untenable.[97] The possibility of the gap between matter and life being bridged entailed the idea of matter being capable of evolution itself. This would require a rethinking of idea of matter as simply passive and inert (with the recognition that perhaps "dead" matter, the kind of matter we often posit as all matter, is but one kind of matter that is at an extreme state of rest). The possibility of empirical research into the origins of life only appears if the strict dichotomy between matter and life begins to blur.

Before Darwin's publication of *The Origin of Species*, spontaneous generation debates concerned present-day organisms, especially animals. Post *Origins*, spontaneous generation also concerned the origin of life. Darwin's conception of a common primordial ancestor of all forms of life implied spontaneous generation at the same as Pasteur dealt a serious blow to the idea (especially in France[98]), which generated confusion on how to reconcile these contradictory views.

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[97] Newtonism, in this context, is not incorrect. Rather, "the old 'universal laws' are no longer universal at all, but apply only to local regions of reality" (Alvin Toffler, "Foreword: Science and Change," in Prigogine and Stengers, *Order Out of Chaos: Man's New Dialogue with Nature*, xiv).

[98] Farley argues that Pasteur's attack on spontaneous generation had a much more significant effect in France than in England and Germany.

Scientific speculation and interrogation of the origins of life only becomes possible after the spontaneous generation debate ceased, and with it, the idea that life continuously arises from matter. On this, Ute Deichmann notes:

> Research on the origin of life, too, became fruitful in the sense of modern science only after it eliminated the ideas of constant smooth transitions between inanimate matter and life and between life forms themselves. Only then the remaining question of how did life come into being though it is not generated on earth now, could be successfully addressed scientifically and possible chemical and physical mechanisms explored.[99]

Although explorations of life is a perennial question, experimental approaches to studying life's origins begin in the early twentieth century. According to historian of science Iris Fry, origins research is premised on a "continuity thesis," or the idea that there is *not* an unbridgeable gap between matter and cellular life.[100] It is only within this framework that a scientific approach to the questions of origins becomes feasible. Experimental research into the origins of life begins in the early-twentieth century. Two key figures involved in this turn are Alexander Oparin (1894-1980) and John Burdon Sanderson (J.B.S) Haldane (1892-1964). A biochemist by training, Oparin published a text in Russian on the question of the origin of life in 1924 which was then translated into English in 1936.[101] Writing in the Soviet Union, he embraced a secular, materialist approach to the question of origins, particularly citing Friedrich Engels' unfinished *Dialectics of Nature* (1883) as a source of inspiration. Rooting his ideas in the colloid chemistry of the early twentieth century, Oparin put forth the thesis that life began with the formation of colloidal

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[99] Ute Deichmann, "Origin of Life. The Role of Experiments, Basic Beliefs, and Social Authorities in the Controversies about the Spontaneous Generation of Life and the Subsequent Debates about Synthesizing Life in the Laboratory," *History and Philosophy of the Life Sciences* 34, no. 3 (2012): 357.
[100] Iris Fry, "Are the Different Hypotheses on The Origin of Life as Different as They Seem?," *Biology and Philosophy* 10 (1995): 389-417; 389.
[101] Alexander Oparin, *Proiskhozhdenie zhizni* [The Origin of Life] (Moscow: Izd. Moskovskii Rabochii), 1924.

coacervates. The consistency of colloids was thought to be similar to the cellular protoplasm (which was itself thought to be a colloidal suspension), and thus the generation of certain colloids was thought to be a possible beginning to life.

Similar to Oparin's materialism, Haldane was an English biochemist who identified as a Marxist and wrote the 1939 preface to Engels' *Dialectics of Nature.* Writing without knowledge of Oparin's 1924 text, Haldane's 1929 paper on "The Origins of Life" closely parallels Oparin's ideas such that their collective ideas are often referred to as The "Oparin-Haldane hypothesis." Both Oparin and Haldane speculated on the geophysical and atmospheric conditions that would have been conducive for life to begin. For Haldane in particular, the cooling of Earth after its formation resulted in a "reducing" atmosphere with very little oxygen. He hypothesized that the impact of ultraviolet light on water, carbon dioxide, and ammonia resulted in the generation of organic compounds, from which proteins could be assembled.[102] While these compounds would have been immediately devoured by organisms on present-day Earth, before the advent of cellular life, these compounds "accumulated till the primitive oceans reached the consistency of hot dilute soup."[103] This rich broth provided nourishment for the first organisms. These early organisms obtained their energy through the process of fermentation (a reaction that does not require oxygen).

Though Oparin and Haldane outlined a similar "soupy" environmental milieu, there are some key differences between their two positions. Whereas Oparin stressed the formation of colloids as being the key to the origins of life, Haldane was influenced by French microbiologist Félix d'Hérelle's discovery of bacteriophages (viruses that infect bacteria), as well as the

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[102] John Burdon Sanderson, "The Origin of Life," (1929), https://www.uv.es/~orilife/textos/Haldane.pdf. Accessed November 10 2019, 7.
[103] Sanderson, "The Origin of Life," 7.

burgeoning field of genetics. Haldane meditated on the different ways in which viruses were being understood by various scientists. For D'Herelle, for example, viruses were living organisms due to their ability to reproduce while Hermane J. Muller, a key American geneticist, thought bacteriophages to be genes and thus intimately related to heredity.[104] Viruses' need of bacteria to grow and proliferate were analogous to how the "first living or half-living things were probably large molecules synthesized under the influence of the Sun's radiation, and only capable of reproduction in the favourable medium in which they originated."[105] Life remained in this virus stage for millions of years before cells acquired the ability to assemble themselves. Oparin and Haldane's respective research papers represent the theoretical approach of how life was thought to emerge in the early twentieth century. The history of origins research in the twentieth century does not end here, and research in the mid-twentieth century will be detailed in the next chapter. What is important to remember for the time being is that the end of spontaneous generation ushered in genuine inquiry into the origins of life. It is in this body of research that a reconsideration of the relation between life and matter can occur, which is a central question for a feminist philosophy of life.

1.9 Matter and Life: The Question of Individuality

If the relation between matter and life is of crucial importance for a feminist philosophy of life, it is useful to track how this question has been taken up by philosophical thinkers interested in biology and evolution in the twentieth century. The relation between matter and life *at the point of cellular emergence* within a thinker's corpus is like a philosophical *litmus test*: it

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[104] Sanderson, "The Origin of Life," 5.
[105] Sanderson, "The Origin of Life," 5.

makes clear whether their claims regarding matter and life can hold. I will demonstrate what I mean by this below by applying this litmus test below.

According to embryologist-turned-philosopher Hans Driesch, studying biology by focusing on the living *individual* is of crucial importance. For Driesch, the "real philosophy of life" is the "philosophy of the individual."[106] This is because "the analysis of individual morphogenesis and of individual inheritance" yields the concept of entelechy—a central idea in Driesch's biophilosophy. [107] Entelechy as it is used for Driesch is a particular kind of *non-energetic* organizing activity in life. "Entelechy is bound to material conditions, not for its existence but in its in effects."[108] Here Driesch is recognizing and accounting for the particular quality of continuity we see in life, and its relation to matter. Vitalism strives to diagnose and cure an understanding of life that is strictly rooted in materialism, especially a materialism that does not see physics and chemistry (or the "inorganic" world) capable of novelty. Therefore what vitalism stresses is that in life, "a *purely* chemical theory of ontogeny" cannot account for how "there any many organs in an organism which have very different specific forms" despite "having the same chemical composition."[109] Studying the chemical makeup of a process, and chemical signals which evoke cellular action, cannot explain the morphogenesis of an organism that is in the process of forming itself. Yet if a concept like entelechy highlights particular features of ontogenesis that a "pure chemical theory of ontogeny" lacks—in other words, what it fundamentally cannot account for—entelechy cannot address how this particular morphogenetic

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[106] Hans Driesch, *The Science and Philosophy of the Organism* (London: Adam and Charles Black, 1908), 324.
[107] Driesch, *The Science and Philosophy of the Organism,* 324.
[108] Hans Driesch, *The Problem of Individuality* (London: Macmillan and Co., 1914), 38.
[109] Driesch, *The Problem of Individuality*, 16.

quality of life itself comes about. In short, it fails to be able to address the question of origins. Driesch himself acknowledges this stumbling block:

> Where this controlling action on the part of entelechy comes from, we do not know at all. We are therefore *absolutely unable to say anything whatever* [*sic*] *about the origin of life*. Life is there, and is transferred from generation to generation in material continuity; and this material continuity means a continuity of systems under control.[110]

Even as vitalism recognizes an important quality of life that strict materialist accounts miss, this doctrine repeatedly stumbles on how to address the origins of life itself. Vitalism cannot address the self-forming properties of atoms and molecules, the raw materials of life that don't seem to be "alive" themselves. A strict division between matter and life—the central tenet of vitalism—cannot hold for a feminist philosophy of life, or in origins scientific research more broadly. The answer origins research largely provides to this dilemma is a concrete and careful exposition of how the chemical components witnessed in life are made from their prebiotic sources. Indeed, the laboratory generation of "vital" substances such as urea (the main component of urine) is represented as a devastating blow to vitalistic theories that argue life is fundamentally a difference in kind from matter.[111] To this point, Henri Bergson highlights materialism's failure to recognize the difference between organic and organized matter. Taking urea as an example, the former is simply an organic residue of a complex bodily process while the latter stresses a kind of ability to self-regulate and construct complexity (and produce by-products through the process).

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[110] Driesch, *The Problem of Individuality*, 38, emphasis in original.

[111] The idea of a specific life force was thought to be defeated by the rise of organic chemistry and the ability to make organic compounds. Sebastien Normandin notes how the "chemical synthesis of urea in 1828" by Wöhler is often branded as the moment that specificity of life's organic compounds is rendered defunct. He also notes how production of acetic acid "by the German chemist Adolph Wilhelm Hermann Kolbe in 1845" may have been an even larger blow (Sebastien Normandin, "Visions of Vitalism: Medicine, Philosophy, and the Soul in Nineteenth Century France (PhD diss., McGill University, 2005), 22.

On this distinction between organic and organized matter, Bergson asks the question: "we make the first now, will we ever make the latter?"[112] While this is useful to think about, it unfortunately reduces the question of life to one of *substance*, and thus repeats the materialist shortcoming of not addressing the particular immaterial or incorporeal quality of life that marks its origin and its continual becoming thereafter. Indeed, the need to evoke an "immaterial" entelechy of vitalism becomes necessary if one understands matter as pure substance.

Vitalism proper has the notion of the individual as its theoretical center, which results in its conceptual limits. To quote Bergson, vitalism fails because "in nature, there is neither purely internal finality nor absolutely distinct individuality."[113] Furthermore, the organizing elements of an individuality must "have themselves a certain individuality, and each will claim its vital principle if the individual pretends to have its own"—which results in there being an endless number of "vital principles."[114] Because there is no strict individuality in nature, Bergson suggests that if there were to be a "vital principle," it would extend far back into the very beginning of life itself:

> [t]he individual itself is not sufficiently independent, not sufficiently cut off from other things, for us to allow it a 'vital principle' of its own. An organism such as a higher vertebrate is the most individuated of all organisms; yet, if we take into account that is only the development of an ovum forming part of the body of its mother and a spermatozoon belonging to the body of its father, that the egg (*i.e.* the ovum fertilized) is a connecting link between the two progenitors since it is common to their two substances, we shall realize that every individual organism, even that of a man, is merely a bud that has sprouted on the combined body of both its parents. Where, then, does the vital principle of the individual principle begin or end? Gradually we shall be carried further and further back, up the individual's remotest ancestors: we shall find solidary with each

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[112] Henri Bergson, "The Metaphysics of Life: From Leçons de Psychologie et de Métaphysique given at Clermont-Ferrand, 1887-88," trans. Michael Vaughan *SubStance* 36, no. 3 (2007): 29.
[113] Bergson, *Creative Evolution*, 42.
[114] Bergson, *Creative Evolution*, 42.

> of them, solidary with that little mass of protoplasmic jelly which is probably at the root for the genealogical tree of life.[115]

Furthermore, the idea of a "vital" impetus of life is in reality only an idea or an image that comes into existence through a difference from matter. A durational concept of life would be of a different order, in which there can never be strict individuality. For Bergson, a non-spatial, non-extended idea of life can only be rendered through from a spiritualist approach. On this, he writes:

> While, in its contact with matter, life is comparable to an impulsion or an impetus, regarded in *itself* it is an immensity of potentiality, a mutual encroachment of thousands and thousands of *tendencies* which nevertheless are 'thousands and thousands' only when once regarded as outside of each other, that is, when spatialized. Contact with matter is what determines this dissociation. Matter divides actually what was but potentially manifold; and in this sense, individuation is in part the work of matter, in part the result of life's own inclination.[116]

The idea of a vital impetus itself comes into being only when life is juxtaposed with matter. If there is a vital principle that can survive the litmus test of origins, it would be a vitalism rooted in matter that would extend back into the very beginnings of life.[117]

To move beyond individuality and vitalism's inability to address origins, the binaristic relation between matter and life must be undone. It is this philosophical undoing of this relation between matter and life that undergirds the continuity thesis that informs all of origins research. That there is never a finished and distinct individual is the answer to the confusion the origins of

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[115] Bergson, *Creative Evolution*, 42-3. Bergson goes on to argue that "[b]eing, to a certain extent one with this primitive ancestor, he is also solidary with all that descends from the ancestor in divergent directions. In this sense each individual may be said to merely united by the totality of living beings by invisible bonds" (43).
[116] Bergson, *Creative Evolution*, 258.
[117] Or, following Raymond Ruyer's development, further complication, and modification of Bergson's ideas, perhaps even before the beginnings of life, to with the emergence of the universe itself.

life poses to vitalism, something that Driesch can sense is a problem, but that his theory fundamentally cannot answer. On this, Elizabeth Grosz reminds us:

> But if the individual is never distinct from or stands over and above the ongoing processes of its development and aging, then any postulate of a vital force will extend well beyond the living, into the intimate connections the living have with the nonliving and, paradoxically, into the very heart of materiality itself."[118]

If there is a vital impetus or principle, it cannot be located in the individual, or even in life. The individual cannot express the relation between matter and life because there is never complete individuality. Indeed, not even life as a whole can encompass a vital principle—it is only in contact with matter that a vital impetus seems to operate, but it crucial to remember that this "impetus" has matter as its source. It is in this reformulation of the relation between matter and life that grounds, as well as guides, this project.

1.10 Chapter Overview

In chapter one, I argue that a principal question that needs to be answered in the origins of life research is the constitution of an *interior milieu* from the outside environment. Life had to invent some way to differentiate itself from its environment, while keeping itself metabolically never-at-rest. I focus on what the conditions of emergence of the first cellular membranes may have been by examining how the concept of a womb is operating in contemporary origins research. Membranes of some sort were crucial to the beginnings of life because they solve what is known as the "concentration" problem in origins research, that is, how to keep pre-biological constituents in close proximity with one another so that they can further react and complexify. In *An Ethics of Sexual Difference*, Irigaray calls attention to how the biological sciences have been slow to study the permeability of membranes, a reservation she directly correlates with the female

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[118] Grosz, *Becoming Undone*, 33-4.

and maternal sexual imaginary. This chapter studies how the concept of "womb" in contemporary origins of life research coalesces with, and can potentially reframe, the relation between matter and life within feminist theory. I concentrate on research that theorizes the origins of cells by considering how the environmental conditions of the Ancient Earth may have facilitated their emergence. This research suggests that cellular life required semipermeable compartmentation, or inorganic wombs, to initially form. Disentangling "womb" from (cis)female maternal bodies, I contend that the far-from-equilibrium hydro-logics of primordial inorganic wombs dissolve a binary relation between matter and life, instead reframing this relation as a difference in degree rather than a difference in kind in the context of the latter's emergence.

The theories of life's origin that I spotlight in chapter one understand embodiment as an irrefutable feature for the emergence of cellularity. The possibility for mammalian forms of "the maternal" are predicated on "the maternal" structure at the cellular level, which requires remarkable interiority. This cellular interiority is a fluid body whereby the first forms of life were able to gestate. The constitution of interiority—of a defined yet permeable boundary between self and other, inside and outside—was *not* an afterthought in the origins of cellular life. A logic of interiority—and the physical compartmentation such a logic requires— was part and parcel of life's emergence from matter. The question that remains is *how* life developed a logic of interiority. Even the most "simple" unicellular membrane is a complex invention because it maintains a difference between self and other that requires chemiosmotic and electrical differences between the inside and outside of the cell boundary.

When explicitly evoked, how is "the maternal" understood and deployed in scientific theory and research? In this chapter, I trace the place of the "maternal" in the geophysical and biochemical origin and evolution of life. After providing a general overview to the field of origins of life research, I demonstrate how the idea of a "primordial womb" works in tandem with the

irreversible bioenergetics of the Earth's geochemical cycles that engendered the conditions for life to emerge. Rather than an anthropomorphism of the natural world, theorizing the fluid dynamics and gestation of life in an inorganic womb shift us away from an idea of biology that gives rise to itself. I outline how the most central problems in initial theories of life's origin in the twentieth century were ones that had to do with concepts that were historically marked in thought and science as "maternal" or "feminine." Attending to the movement and forces of fluids fundamentally reorients the emergence of life from matter.

Chapter two theorizes what metabolism within a feminist philosophy of life would entail. I argue that a "litmus test" for a metabolism of a feminist philosophy of life would not just theorize the metabolism of present-day life already in existence; but would be able to address *how metabolism itself came into being*—a much more difficult question. I begin by outlining how metabolism can be understood through two approaches: equilibrium thermodynamics and *non*equilibrium thermodynamics. The former approaches metabolism through the concept of *energy* (as an external source injected into a system), and analyzes metabolism as a series of states. I contend that a feminist philosophy of life would *not* understand metabolism through equilibrium thermodynamics because this framework is rooted in the study of *discrete states* rather than processes, and therefore would be fundamentally incapable of theorizing the beginnings of proto-metabolism itself.

Instead, metabolism is about *the dissipation of disequilibria* and *the flow of entropy* rather than energy. As such, a feminist philosophy of life would root itself in *non*equilibrium thermodynamics. Instead of external packets of energy being fed into a system, metabolism only arises through what is known as thermodynamic *coupling* between a large entropic process set on its dissipation and a smaller, "uphill" process that depends on the former process to be driven into order. Metabolism is a process that can be understood as a series of conversions of

disequilibrium, rather than inputs of energy that move a system from one static state to the next. Disequilibria are rooted in an irreducible interaction between two or more "opposing" processes in tension. Energy transfer, in contrast, is usually thought of in the singular—as a force that externally acts upon something to initiate change. Though this difference between theorizing disequilibria and energy may be overlooked in an already formed biological body, it crucial to note that it cannot be ignored in the emergence of cellular life itself.

I start the chapter by analyzing Myra J. Hird's suggestion that "metabolism as ontology" is a more capacious theoretical framework than the ontology of sexual difference for a feminist engagement with the natural world. Hird argues that metabolism may collapse the life/nonlife bifurcation. This chapter challenges the idea that "energy" can explain metabolism, or that life forms such as humans eat to "unleash" energy in food. It does so using scientific research which argues the role of entropy has been grossly misunderstood in the emergence of life, and that entropy, rather than energy, is metabolism's condition of emergence. Specifically, I examine how a non-anthropocentric conceptualization of a logic of sexual difference opens up the possibility of understanding the emergence of metabolism. If sexual difference explodes any and all notions of "oneness" as the conditions of thought and the natural world, this chapter speculates on how a logic of *at least two* can help generate a novel way of understanding the relation between entropy and order in relation to metabolism. I do this through a consideration of Elizabeth Grosz's concept of sexual difference as an *engine of creation* and life itself. I connect this idea to far-from-equilibrium origins research that argues that the question of how life emerged as an orderly state can be reimagined through a reformulation of the concept of entropy through the concept of a *maternal* engine. This reimagining of entropy as a maternal engine that seeks to dissipate itself allows for less-probable reactions to be "driven" in existence, including the proto-metabolic reactions necessary for organismic closure. Though the idea of "maternal engine" is a metaphor,

the logic it elaborates—a logic of at least two—is the logic of the real; it is a dynamic force that brings metabolism into existence. Such a concept of maternal engine reframes the very idea of self-organization by challenging the very idea of a "self" that can organize. This is because this instantiation is reframed as the movement a maternal engine itself produces. A maternal engine set solely on its own entropic movements creates self-organized critical components for the metabolism of life as a *byproduct*. My argument therefore elaborates an Irigaryan logic of the maternal that does not only solely operate for the generation of life. In other words, the maternal here does not simply serve the needs of a "child" daughter engine; it first and foremost is attuned to the maternal engine's self-becoming, and thereby not does reduce the maternal to a reproductive function.

Chapter three considers the question of how the first genetic systems came about on the Early Earth. I build on feminist critiques of the figure of the "gene" and specifically DNA, and decenter the privileged center DNA holds in biological research (and culture more broadly) by focusing on the "RNA world," a hypothetical time period before the emergence of cellular life in which RNA, rather than DNA, was the primary genetic material. Through a focus on RNA, this chapter displaces the centrality DNA is given in discussions regarding cellular emergence. The idea of a hypothetical RNA world is thought to solve the chicken-or-egg conundrum. At the molecular level, this problem exists as follows: if DNA, a structure that is remarkably stable and inert, cannot replicate itself without proteins, how did the first genetic systems arise *if* they were primarily DNA-based? A speculative "RNA world" offers one possible solution to this problem. This is because research from the 1980s to the present has demonstrated that RNA has strange and interesting formative properties: RNA can be *both* a source of information storage as well as a catalyst that can splice (or cut) itself, thereby presenting a possible solution to how genetics may have come into being.

I first present research that utilizes a "top-down" approach for such a world. Such an approach scans contemporary living forms for "vital clues" that an RNA world may have existed before DNA-based cellular life. The central role RNA plays in present day ribosomes (cellular factories that build proteins), as well as its ability to catalyze its *own* formation (something that is impossible for DNA to do), are contemporary clues that RNA has capabilities that could have made it a critical nucleic acid in the origins of cellular life. From here, I then turn my attention to "bottom-up" research that focuses on generating RNA molecules *de novo*, an experimental analogue to how RNA may have operated in the origins of life. Such bottom-up approaches run into a whole host of issues, all of which have to do with the concept of *invention,* elaboration and continuous generation of *living form*. I suggest that the RNA world cannot be recreated in laboratory experiments because *living form*—i.e., the self-making, self-splicing, and inventive properties of RNA—cannot be created "from scratch" in a piecemeal fashion within a laboratory. From here, I explore how viruses and viral-like entities known as viroids are considered by some scientists to be connected to the RNA world. I suggest that viroids help us conceptualize the RNA world because they are, to use French philosopher of biology Raymond Ruyer's terminology, primary forms that are self-making, and thus possibly explain how living form of RNA itself came into being.

Chapter four continues to map out the centrality of the concept of living form in the emergence of life, and does so by linking it to the question of morphogenesis and memory. If matter is never devoid of form—in other words, if we begin with a framing of matter that is not passive or inert—how can we reimagine the relation between matter and life? I turn to Raymond Ruyer's ideas again in this chapter. By rooting his theory in the revolutions in physics that take place in the early twentieth-century that fundamentally reorient what matter is, Ruyer presents a theory of matter that is never passive. Here, matter becomes a *structuring activity* rather than a

static atemporal object lacking dynamism and, moreover, matter is never without form. Matter, for Ruyer, has temporality as an inherent property.

The chapter takes up this Ruyerian framing of matter as a point of entry to ask how memory or heredity begins *before* cellular life. The question of the relationship between matter and memory is a central question that must be addressed to understand the emergence of cellular life, and provides us with the resources to understand how chemical morphogenesis unfolds the possibility for organic morphogenesis. Ultimately, what is perhaps most intriguing to think with Ruyer is how "life" is a not a central or privileged concept in his work; the genesis of living forms develops a continuity between (certain) physical and chemical forms and living ones, and does so by focusing on what is common to them all, namely, that they are primary forms, that is, self-producing and inseparable from their actions.

This chapter continues to think through viruses in the emergence of cellular life to theorize how ontogenetic memory might have begun, a crucial invention in the history of life. Through Ruyer's conception of primary forms, I ask how viruses as primary forms coalesce with contemporary virological research that understands viruses and viral-like entities as crucial agents in evolution. Rather than focus on debates on whether concretely locate viruses as "living" or "non-living," I use Ruyer to ask (what I consider to be) a much more interesting question of how the liminal characteristics of viruses, combined with how they are primary forms, provide the grounds to understand how memory and reproduction may have unfolded over the course of evolution. That viruses do not have an "definite individuality," something that is particularly evident in viral self-replication, signals to Ruyer that viruses are in touch with a transspatial domain that places them in circuit with themes that can guide self-making activities that embody the concept of living form.

Chapters three and four demonstrate that a feminist philosophy of life would not only address the material and spatiotemporal conditions of emergence, it would rethink the concept and kind of form that is allowed to unfold in these conditions. It therefore would dynamize how not only we understand matter, but also how the relation between matter and form, or matter and idea, can be rethought to attend to the complexity that marks all of life.

What I am studying in these four chapters concerns the most fundamental questions of biology. The constitution of a membrane, the beginnings of metabolism, and the emergence of genetics are the conditions of cellular life itself, as well as the conditions for noncellular forms of life such viruses and viral-like entities to exist. Ultimately, this project is an exercise in what feminist theory can do and what it can address. While I may not be able to definitely say exactly how life originated (and neither can science for that matter), I do firmly assert that central principles related to nature, reality, and biology that have been explored in feminist theory—such as womb, entropy, maternal, milieu—are the ontological conditions of life's emergence, as well as its further elaboration. Life's origins were not phallocentric (rooted in the valuing of one term, one mode of being at the expense of another). Nor can a binaristic relation between matter and life explain emergence. A feminist philosophy of life would express the nature of reality, its fluid logic, and through this, seamlessly be able to unfold the origins of cellular life itself.

2. The Conditions of Emergence: Irigaray, Primordial Wombs, and The Origins of Cellular Life

2.1 Introduction: Life's Matrix

It is often assumed that because the emergence of life began with single-celled organisms, and single-cellular organisms can reproduce asexually, that concepts associated with reproduction in the human or mammalian realm, such as the notions of womb or gestation, have no bearing on life's origins. This chapter considers how the concept of "womb" in contemporary origins of life research has the potential to reorient how we theorize the emergence of cellular life from matter and the philosophical implications this reorientation can have on feminist theory. I hone in on a particular strand of origins of life research, one that uses the far-from-equilibrium thermodynamics of inorganic wombs to destabilize a binary and hierarchical relation between life and matter framed through the lens of activity and passivity, respectively. Instead, the relation between these two terms in the wombs operating in deep-sea vents is one where these semi-permeable compartments are thought to provide the complex thermodynamic and chemical conditions for cellular life to begin, somewhere between 4.4 and 3.8 billion years ago.[1] In doing so, the relation between matter and life can be rethought from a difference in kind to a difference in degree in the context of the latter's initial emergence from matter.

Throughout the chapter, I link contemporary origins-of-life research with Luce Irigaray's philosophy of sexual difference, paying close attention to moments in her corpus where she meditates on the biological sciences. I place Irigaray's nuanced intuitions concerning biology

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[1] William Martin and Michael J. Russell, "On the origins of cells: a hypothesis for the evolutionary transitions from abiotic geochemistry to chemoautotrophic prokaryotes, and from prokaryotes to nucleated cells," *Philosophical Transactions of the Royal Society of London B* 358, no. 1429 (January 2003): 59-60.

alongside contemporary origins-of-life research in order to demonstrate how they surprisingly confirm each other's intuitions on the conditions of emergence for life. I substantiate Irigaray's discernments regarding the "mechanics" of fluids, the potential of disequilibrium, and the importance of the "permeability of membranes" by outlining how her ideas are affirmed in geochemically rooted origins of life research, which theorizes the emergence of cellular life in and through the far-from-equilibrium hydro-logics of semipermeable inorganic wombs. I use hydro-logics here as a rhetorical play on hydrology, the scientific study of the movement and flow of water on the Earth. Such a hydro-logics would not perpetuate a phallocentric logic of sameness that operates through binary oppositions. It would instead be a *contiguous* logic of relation where beings "touch on one another, without merging into one"—a kind of logic that not only coincides with the "mechanics" of fluids but can also "represent the co-existence of irreducibly different beings."[2]

My goal in this chapter is not to present a holistic overview of the contemporary origins of life research (though the strand I detail below, which centers around what is known as alkaline vent theory, or AVT, continues to gain attention and critical appraisal by the wider scientific community). Instead, I trace how *certain* geochemically informed strands of origins of life research coalesce with Irigaray's writings.[3] It should be noted that origins of life research is a largely speculative field due to its central object of study. That being said, the ways in which the relation between matter and life are framed in the latter's emergence should be of critical concern to feminist theorists, as this relation can either rely on a sexed hierarchy, where life animates dead

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[2] Rachel Jones, *Irigaray: Towards a Sexuate Philosophy* (Malden, MA and Cambridge: Polity Press, 2011), 85.
[3]For a broad overview of twentieth century origins of life research in the twentieth century, see Fry (2000).

matter, *or* alternatively, can reimagine the relation between these two terms that signals the development of an alternative formulation of both matter and life. The question of where we come from is one that we cannot but ask. Indeed, for Irigaray, acknowledging our origins—where we come from, what makes us possible, what and where we may have once gestated within—is an utmost ethical concern because it signals a debt to the maternal that we can never repay.

As I outlined in the introduction, the etymological roots of "matrix" originate in the maternal. Irigarayan scholar Irina Aristarkhova argues "matrix" and "maternal" are so deeply intertwined that "matrix is 'ground zero'; it is *the* origin; it is that original *place*/space of generation and becoming."[4] Aristarkhova reminds us that matrix's "connection to origin and generation was etymologically embodied in one of its oldest usages—'a pregnant animal.'"[5] In its earliest Latin uses, "matrix" refers to both "pregnant animal" and "breeding female" as well as to *mater*, the root of "matter" and "mother." "Matrix" subsequently begins to coincide with "womb" by the first millennium CE.[6] A matrix can be defined as "a place or medium in which something is originated, produced, or developed; the environment in which a particular activity or process begins; a point of origin and growth."[7] Furthermore, matrix is "a supporting or enclosing structure."[8] Thus, this concept is marked with "female," "mother," "womb," "structure," "medium," as well as a point of origin.

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[4] Irina Aristarkhova, *Hospitality of the Matrix: Philosophy, Biomedicine, and Culture* (New York: Columbia University Press, 2012), 2, emphasis in original.
[5] Aristarkhova, *Hospitality of the Matrix*, 2, emphasis in original.
[6] Aristarkhova, *Hospitality of the Matrix*, 12.
[7] "matrix, n." OED Online. June 2017. Oxford University Press. http://www.oed.com.proxy.lib.duke.edu/view/Entry/115057?rskey=VqmYYl&result=1 (accessed October 26, 2017).
[8] "matrix, n."

This chapter foregrounds the relation between "maternal" and "womb" while simultaneously untangling this gestational, generative space from cis-female human embodiment. While maternal-wombs are often associated with cis-female bodies, using the hydro-logics of inorganic wombs, I reframe the "maternal" in a thoroughly pre-human, non-anthropomorphic evolutionary sense. Collapsing "womb" and/or "maternal" with cis-female bodies risks an anthropomorphization of embodiment more generally, as human cis-female bodies neither invented the concept of birth or womb.

Defining "exactly" what life "is" is a notoriously difficult task that continues to be debated in origins research and the philosophy of science. That being said, the particular feature of cellular life that concerns me here is how life is a far-from-equilibrium thermodynamic process. My wager is that this thermodynamic complexity could have only initially been birthed by an inorganic matrix that provided the same thermodynamic gestational conditions. As such, I put Irigaray in conversation with contemporary origins research to provocatively suggest that the complex thermodynamic processes within cellular life were only able to come into being by gestating in far-from-equilibrium inorganic wombs. In doing so, I foreground the question of embodiment as the conditions of emergence for life: perhaps life is such a complex process that it, even at the level of a single cell, involves a kind of thermodynamic ingenuity that could not *initially* be *self*-made or sustained.

In what follows, I understand cellular life as a process that requires "compartments separated from their surroundings that spontaneously multiply with energy gleaned through self-contained, thermodynamically favourable redox reactions."[9] Redox reactions are a specific kind of chemical reactions (of critical importance within biological systems) in which there is a flow

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[9] Martin and Russell, "On the origins of cells," 63.

or "transfer of electrons from an external donor to an available acceptor."[10] Batteries involve redox chemistry as do the most fundamental thermodynamic features of cellular life. I think about the specific, unceasing chemistry cells perform to harness energy in order to stay alive in order to speculate how the origins of these complex biochemical processes may have been first engendered by the Earth's geochemistry. Though this can lend itself to thinking about the origins of cellular metabolism quite seamlessly, due to limitations of space, I will use Irigaray and origins research to outline how primordial inorganic wombs could have provided *the conditions of emergence* for cellular metabolism, and subsequently genetics, rather than directly focusing on these questions themselves.[11]

I begin the chapter by juxtaposing two hypothetical environmental settings that have had key roles in theorizing the origins of life: prebiotic soup theory and deep-sea vents. I contend that origins research around deep-sea vents work in tandem with Irigaray's marking of fluidity and far-from-equilibrium thermodynamics as concepts that cannot be adequately understood or represented using phallocentrism's "ruling symbolics."[12] Following this, I hone in on origins research that theorizes how primordial wombs could have fulfilled two key conditions for cellular life to emerge: first, the compartmentation they provide could solve what is known as the concentration problem in origins research and second, the far-from-equilibrium geochemical processes that generated these semipermeable wombs could also provide the geochemical

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[10] Martin and Russell, "On the origins of cells," 63.
[11] My insistence on an ordering that begins with the conditions of emergence from some kind of proto-metabolism that *then* generates genetic systems is based on geochemical and thermodynamic oriented origins research that argues "no nucleic acid evolution is possible without a supporting geochemistry, later biogeochemistry and finally biochemistry to provide a steady flow of adequate concentrations of polymerizeable precursors (for example nucleotides) and thus to underpin any sort of replication" (Martin and Russell, "On the origins of cells," 64).
[12] Irigaray, *This Sex Which is Not One*, 106–7.

gradients for the beginnings of redox chemistry to come into being, thereby providing the conditions for the birth of biochemistry.

2.2 Geochemistry as The Conditions of Life

A single cellular life form (such as a bacterium) is an evolutionary invention in the most profound sense: it maintains a difference between self and other, a tremendous feat which requires complex electrochemical differences in the form of gradients to be actively maintained at its membrane. A concentration gradient can be defined as a difference in concentration of something (such as a hydrogen ion) on either side of a boundary (like a membrane); this difference is replete with potential energy that can be used to drive cellular work, and thus could not be further from a static, "lifeless" wall. In fact, a cell that ceases to maintain a chemical and electrical heterogeneity between itself and its environment is no longer a cell, but rather a dead remnant of something that was once living. The far-from-equilibrium complexity sustained across single-cellular membranes raises the question in origins of life research of how this thermodynamic intricacy came about. Is it possible for one to self-make such a heterogeneous boundary between self/other oneself, particularly, if there cannot be a "self" without this boundary? If the emergence of cellular life requires the invention of such a far-from-equilibrium boundary to drive chemical processes, before there is genetics to code for such membranes, can such an activity be self-created? Or can it only be generated if it first gestates in an *other*, perhaps a complex, aquatic *milieu* or environment, which is also far-from-equilibrium?

The most famous experiment concerning the origins of life is the 1952 Miller-Urey Experiment done by the then graduate student Stanley Miller (1930- 2007). Miller's dissertation advisor, Harold Urey (1893- 1981) was a Nobel Laureate whose research considered the makeup

of the Earth's primordial atmosphere.[13] After finally persuading his mentor to allow him to put his (mentor's) ideas to the test, 23 year old Miller designed an experiment simulating (what he thought was) the primitive atmosphere and watery surface of the Earth. This experiment demonstrated that simple inorganic gases, under the right conditions and with an input of an energetic source, can result in organic compounds. The biochemical building blocks for nucleic acids were able to be synthesized within a laboratory. Miller designed a table top glass apparatus that would simulate an electric discharge ("lightning" produced by 2 tungsten electrodes) striking a "primitive ocean" (a small, 5-inch diameter 300 milliliter flask) filled simply with methane (CH_4), ammonia (NH_3), and hydrogen gas (H_2). The water in the flask was boiled and the spark was run through the "ocean" for seven days. After organic chemical analysis, Miller was certain that the amino acids glycine, α-alanine and β-alanine were present. (Aspartic acid and α-aminobutyric acid (AABA) were also possibly detected but this could not be definitively confirmed by Miller). Because they are the precursors (i.e., ingredients needed for the recipe) of life, to mark amino acids as signs of life themselves would be problematic. But before Miller's experiment, the idea of the precursors to life being created *in vitro* was not believed possible.[14] While there is still to this day intense debate within origins of life research about the precise makeup of the primitive atmosphere of the Earth, Miller's experiment nonetheless opened the way for scientific research into a topic that was thought to be impossible to directly study. The

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[13] Urey's principal point of inspiration came from the Soviet scientist Alexander Ivanovich Oparin (1894-1980). In 1924, Oparin, also considered one of the foundational figure in origins of life research, published a pamphlet called "*The Origin of Life"* in the Soviet Union that was not translated into English until 1968.

[14] An experiment that is seen by many as a source of inspiration to experimenting with the precursors of life is the Friedrich Wöhler (1800-1882) creating urea—an organic compound thought to only be produced by animal kidneys—within his lab. By heating ammonium cyanate (NH_4CNO), Wohler accidentally created crystals of urea $CO(NH_2)_2$ (Lynn Margulis and Dorion Sagan, *What is Life?* (New York: Simon and Schuster, 1995), 29).

success of Miller-Urey experiment led to the creation of the field of prebiotic chemistry and laid the foundation for empirical inquiry into the origins of life.

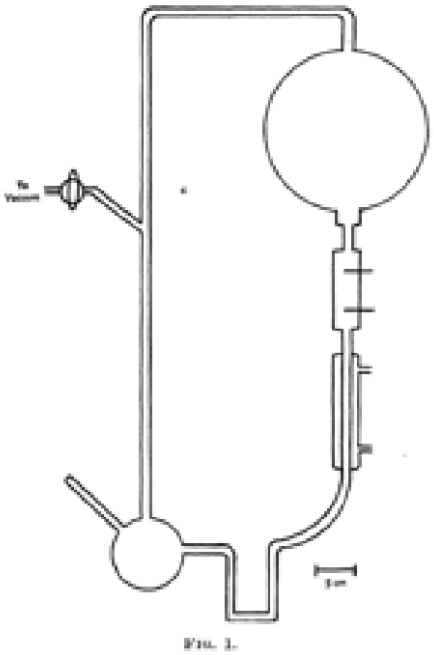

Figure 1: Diagram of Experimental Apparatus published in *Science* (Miller, 1953)

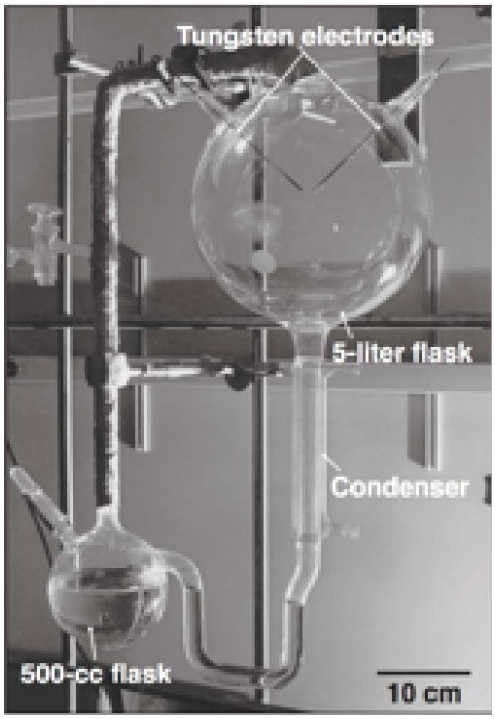

Figure 2: Picture of Apparatus Used in original Miller experiment (Bada and Lacanzo, 2003)

In addition to its successes, however, the Miller-Urey experiment has been also intensely criticized. The first critique centers on the primitive atmospheric Miller simulated in his experiment, specifically its gaseous components. Miller based his atmosphere composition on his mentor's speculations that early atmosphere was highly reducing—which, among other things, means it was largely devoid of oxygen.[15] It is only in the absence of oxygen that an atmosphere

[15] This refers to an entire section of chemistry referred to as redox, or reduction-oxidation actions, which refers two kinds of chemical reactions, reduction and oxidation, that involve the transfer of electron(s) from one atom, ion, or molecule that is/are gained by another atom, ion, or molecule. Oxidation refers to the loss of electrons or increase in oxidation of electrons while reduction refers to the gain of electrons (Concepción Alonso, "Oxidation," in *Encyclopedia of Astrobiology*, Muriel Gargaud, William M. Irvine, Ricardo Amils, Henderson James Cleaves, Daniele Pinti,

like the one Miller simulated could have existed. By radioactively dating extremely small but hardy minerals called zircons (which are the only direct remnants of early earth), scientists at Rensselaer Polytechnic Institute have challenged Miller's reducing early atmosphere of the Earth. They argue that Miller's atmospheric composition neglects to take into account the role magma (and its vapors) erupting from deep within the Earth had upon the early atmosphere. While there is general scientific consensus that the early Earth's atmosphere did not have free oxygen gas (O_2), many argue that this does not mean it was a reducing atmosphere either. Instead, it is very likely that the early Earth had "an atmosphere dominated by the more oxygen-rich compounds found within our current atmosphere — including water, carbon dioxide, and sulfur dioxide."[16]

Scientists have also brought critical attention to the source of energy in the Miller experiment: an electric spark. Though the sun's rays were only 70% as powerful as they are today, the more pressing question in relation to the surface-ocean environment of the Miller experiment is that solar radiation would not only create simple biomolecules but would also denature them as well. This would therefore largely destroy the possibility of these biomolecules (the precursors of life) to further react to form longer chains called peptides. A third critique concerns the ocean *surface* as the milieu for life's cellular beginnings. A theory of cellular life that begins at ocean surface neglects to account for how these organic precursors could have survived frequent attacks from comets and asteroids in the geological phase of the Earth known as the "period of heavy bombardment." The fourth major critique relates to the question of how simple biomolecules can become more complex: given how Miller and his research team insisted

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Josâe Cernicharo Quintanilla, and Michel Viso, eds., (Heidelberg: Springer Berlin Heidelberg, 2019), 1194.

[16] Daniella Scalice, "Earth's Early Atmosphere: An Update," NASA Astrobiology Institute. https://nai.nasa.gov/articles/2011/12/2/earths-early-atmosphere-an-update/.

that these reactions began at the ocean surface, in the vast expanses of the primordial ocean, the products of the simple reactions could have easily moved *away* from one another instead of staying close enough together to undergo further chemical complexification.[17] While the Sun and its photochemical energy do play a large role in the history of contemporary life on the planet, there is growing consensus that the photochemical origins of life on the surface of the early volatile Earth, while able to create simple chemical precursors of life, was *too* volatile to keep these chemicals further sustain these chemicals and keep them "alive." The chemical precursors in this scenario would fail to be in close enough proximity to further react with one another, and their presence at the ocean's surface would have made them extremely vulnerable to external chemical and physical threats.

Since the 1920s, "primordial soup" or "prebiotic broth" theory has been the most prominent scenario for the origins of life.[18] According to this theory, "UV radiation provided the energy to convert methane, ammonia and water into the first organic compounds in the oceans of the early Earth. In the absence of life forms to consume them, these molecules accumulated to the concentration of a 'hot dilute soup,'"[19] making the ancient ocean a nutritive broth for the first

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[17] Aware of this critique, Miller has argued that the primordial ocean surface could have had UV absorbers in the form of "prebiotic organic polymers [themselves formed from electrical discharges] as well as several inorganic compounds are sufficient to protect oceanic organic molecules from UV degradation" (Cleaves and Miller, "Oceanic protection of prebiotic organic compounds from UV radiation" *Proceedings of the National Academy of Sciences of the United States of America* 95, no. 13 (1998): 7260).

[18] The "primordial soup" theory was independently proposed by Soviet scientist A.I. Oparin and British geneticist J.B.S. Haldane in two separate (but theoretically similar) papers in the 1920s. See Alexander Ivanovich Oparin, *The Origin of Life* (Moscow: Moscow Worker Publisher, 1924) as well as John Burdon Sanderson Haldane, "Origin of life" *Rationalist Annual* 148 (1929): 3-10. The first book-length English translation of Oparin's work is *The Origin of Life on Earth* (New York: Macmillan, 1938).

[19] Nick Lane, John F. Allen, and William Martin, "How did LUCA make a living? Chemiosmosis in the origin of life," *BioEssays* 32 (2010): 271.

living forms to devour. Prebiotic broth speculations assume a heterotrophic origin of life. As the prefix *hetero* implies, a heterotroph needs to obtain food and energy (in the form of organic compounds) from an exterior source. In heterotrophic scenarios of the origin of life, then, the first living entities were provided "sustenance" (reduced carbon compounds) in the ancient oceanic broth. It was only *after* they fully consumed their original nutritional sources of carbon that these hypothetical living entities developed *auto*trophic ways to generate organic carbon compounds from inorganic sources such as carbon dioxide.

In order to generate and further transform the prebiotic components of life, heterotrophic scenarios often center around chemical reactions that no form of extant cellular life (as far as we know) uses. For this reason, many biologists are skeptical of heterotrophic theories due to the large gap they generate between the chemistry that life required at its onset and what it continues to use today.[20] Furthermore, heterotrophic origin scenarios are often are incompatible with what is known about the geology and geochemistry of the infant Earth given how they often seem to require conditions that were unlikely to have existed. They also have a much less specific (perhaps *un*specific) idea of the particular environment in which life might have begun (often somewhere in the ancient sea or tidal zones). One of the most pressing problems "soup" theories have difficulty answering concerns how the "broth" is at thermodynamic equilibrium. Once the particular chemical precursors of interest have initially reacted from their initial external input or "spark" of energy, they cease to further react and complexify. The reason the chemical precursors are "reluctant to react further in a soup is that they are at thermodynamic equilibrium."[21] A system operating *at thermodynamic equilibrium* fails to provide the energetic conditions that the

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[20] Peter Schönheit, Wolfgang Buckel, and William F. Martin, "On the Origin of Heterotrophy," *Trends in Microbiology* 24, no. 1 (January 2016): 12, http://dx.doi.org/10.1016/j.tim.2015.10.003
[21] Lane, Allen, and Martin, "How did LUCA," 272.

emergence of cellular life requires, for such a system is devoid of the disequilibria needed to sustain the ceaseless chemistry we understand as life. Instead of cellular emergence requiring a singular "spark" of energy, the far-from-equilibrium thermodynamics it requires signals that "what life needed was not some harsh and problematic source of energy like UV radiation (or lightning), but a continuous and replenishing source of chemical energy."[22]

In contrast to a "prebiotic soup" and heterotrophic origin of life, autotrophic theories suggest life was able to generate its own sources of organic carbon and energy since its inception. Autotrophic scenarios tend to posit very specific material and environmental conditions for life's emergence. They are most often set in deep-sea hydrothermal vents. Since their discovery in 1977, deep-sea hydrothermal vents have become important sites for theorizing the origins of life because of how they fundamentally reframed scientists' understanding of where and how life could exist. Researchers found aquatic life ranging from small bacteria, feeding on natural sources of sulfur, to plant and animal life. Because plate tectonics theory predicted the existence of hydrothermal vents, scientists were most surprised about the entire living ecosystems existing around the vents rather than the actual vents themselves.

Before witnessing hydrothermal vents sustaining life and entire ecosystems through geochemical energy, scientists assumed that all life requires photosynthetic energy from the Sun to exist. Microbes are the primary producers of the food web of vent ecosystems. They perform chemosynthesis for their metabolic needs, harnessing and converting geochemical energy into organic compounds. Photosynthesis and chemosynthesis are similar in that they are both processes where inorganic sources of carbon (like CO_2) are transformed into organic carbon

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[22] Lane, Allen, and Martin, "How did LUCA," 272.

(biomolecules that are energetic sources, in other words, food). Photosynthesis uses the sun's energy to drive this reaction while chemosynthesis uses chemical energy generated from the Earth's own geothermal and geochemical reserves. While the process of chemosynthesis was known since the late nineteenth century, it "was considered to play no significant, quantitative role in the carbon cycle of the photosynthetically dominated Earth's surface…the biogeochemical significance of chemosynthesis emerged only upon discovery of deep-sea hydrothermal vent systems"[23] where an alternate production of organic carbon from inorganic sources become apparent. The recognition of how microbial life could harness the intense amounts of geochemical energy available at these sites thus spurred intense speculation on how similar vents themselves could have been "chemically 'reactive' hatcheries for the origins of life."[24]

The environmental setting, available energy, and particular chemical materials for life's emergence directly mold our conception of LUCA, the last universal common ancestor of life before its first major evolutionary divergence into the lineages of archaea and bacteria.[25] LUCA is the theoretical organism and space between "non-life" and "life." We have no direct access to LUCA—there are no "fossils" of it for us to study. Instead, the nature and characteristics of LUCA are reconstructed based on logical inferences, especially using phylogenetic analysis, a

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[23] Cindy Van Dover, *The Ecology of Deep-Sea Hydrothermal Vents* (Princeton, NJ: Princeton University Press, 2000), 117

[24] Martin and Russell, "On the origins of cells," 63. On early speculations linking hydrothermal vents to the origins of life, see Corliss et al. (1981). Miller and Bada (1988) are among the earliest and most well-known critics of this hypothesis.

[25] Archaea and bacteria are both prokaryotic, meaning that they do not have organelles or a membrane-bound nucleus. The third domain of life, Eukarya, of which multicellular life such as humans are a part, *do* possess organelles and a membrane-bound nucleus. Eukaryotes are evolutionary descendants of an ancient symbiotic merger between archaea and bacteria that occurred only 2.7 billion years—making them a much more recent evolutionary invention (Geoffrey M. Cooper, *The Cell: A Molecular Approach*. 2nd edition. Sunderland (MA): Sinauer Associates; 2000. The Origin and Evolution of Cells. Available from: https://www.ncbi.nlm.nih.gov/books/NBK9841/).

technique greatly enhanced by contemporary digital genomic databases. Though many aspects of LUCA continue to be debated, there is wide consensus that in addition to a working metabolism, LUCA possessed some sort of genetic code (though the details of *which* genes are actively still being debated) as well as a ribosome (a molecular machine that synthesizes proteins across cellular life—and a central object of concern in chapter three).[26]

A key insight regarding LUCA, one that I will later connect to primordial wombs, can be ascertained by thinking about archaea and bacteria as the two most ancient prokaryotic lineages of life. (Eukaryotes—which include plants and animals such as humans—are evolutionary descendants of an ancient symbiotic merger between archaea and bacteria that occurred *only* 2.7 billion years and thus are irrelevant to our theorizing LUCA here.[27]) Archaea and bacteria have universal bioenergetics *yet* different membranes compositions (depicted in the figures below).

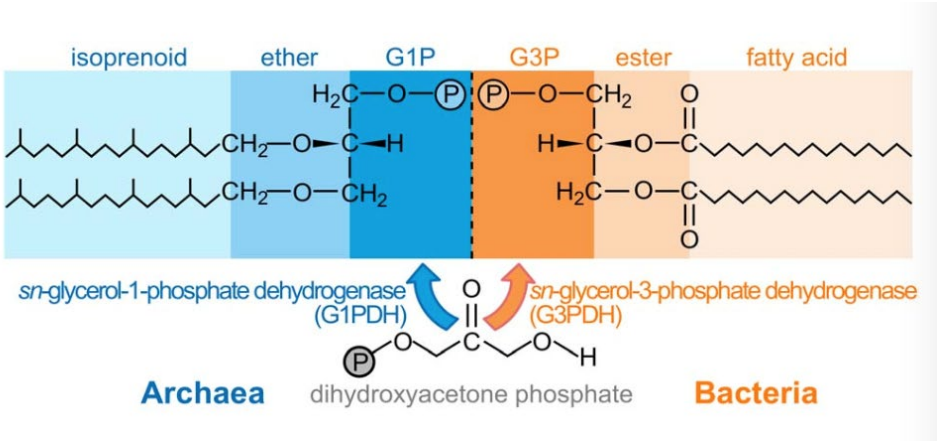

Figure 3: Membrane lipids of Archean and bacteria (Sojo et al., 2014)

[26] Madeline C. Weiss et al., "The physiology and habitat of the last universal common ancestor," *Nature Microbiology* 1 (2016): 16116.
[27] Cooper, "The Origin and Evolution of Cells."

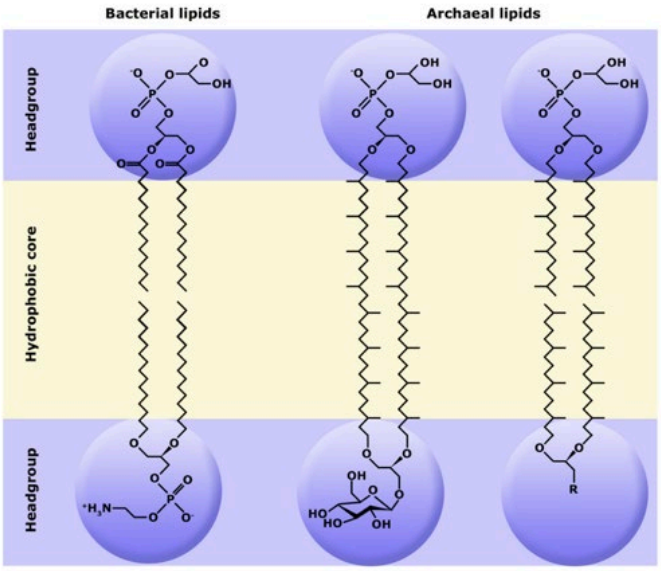

Figure 4: Membrane lipids of Archean and bacteria (Sojo et al., 2014)

Archaeal and bacterial membranes share a fundamental similarity in how they are amphiphilic: they both have exterior "heads" that are hydrophilic and are attracted to water and the interior "tails" are hydrophobic and have an aversion to water. The amphiphilic structure of both membrane compositions allow for the spontaneous self-organization of a membrane once its chemical components are formed. The chemical composition of bacteria and archaea lipid "tails" differ: archaeal lipids are composed of repeating isoprene units while bacteria lipids use fatty acids. The "heads" have a chemical similarity but are enantiomers (or mirror-images) of one another and therefore not superimposable. In addition, the bonds that connect the lipid tails to the "head" differ: archaea membrane lipids have chemical bonds called *ether* bonds while bacteria

lipids have *ester* bonds. Furthermore, bacterial membranes are "bi-layers" while archaeal membranes can be composed of "bi-layers" or, in some cases, "mono-layers."[28]

Despite their membrane bioenergetics being universal, their respective phospholipid membranes "are *fundamentally different*."[29] In other words, though the bioenergetic reactions that occur across their membranes are the same and the orientation of their membranes are congruent (they have a hydrophilic exterior and hydrophobic interior), the actual chemical architecture of bacterial and archaeal membranes themselves vastly differ. This similarity in their bioenergetics combined with their vastly differing membrane composition suggests that LUCA did not have a "true" cellular membrane itself, for if it did possess a "true" cellular membrane, such an important aspect of life would likely been conserved in its two major evolutionary offspring.

A possible connection between LUCA's membrane chemistry and the early Earth's geochemistry emerges in recent phylogenetic research. An in-depth 2016 study concludes that LUCA was an autotroph that was "only half-alive" in the sense that it was "dependent upon geochemistry."[30] Reconstructing LUCA's "microbial ecology,"[31] in other words "how and where LUCA lived,"[32] researchers argue that LUCA inhabited a thermophilic hydrothermal setting. In addition, LUCA possessed an ATP Synthase, an enzyme (or biological catalyst) that can "harness ion gradients for energy metabolism."[33] As a microscopic rotary machine, ATP Synthase generates adenosine triphosphate, or ATP, the "energy currency" of cellular life. It does this by harnessing the

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[28] The monolayer lipid membranes tend to be found in archaea that live in extreme environments.
[29] Victor Sojo, Andrew Pomiankowski, and Nick lane, "A Bioenergetic Basis for Membrane Divergence in Archaea and Bacteria," *PLOS Biology* 12, no. 8 (2014): e1001926, emphasis added.
[30] Weiss et al., "The physiology and habitat of the last universal common ancestor," 16116.
[31] Weiss et al., "The physiology and habitat of the last universal common ancestor," 16116.
[32] Weiss et al., "The physiology and habitat of the last universal common ancestor," 16116.
[33] Weiss et al., "The physiology and habitat of the last universal common ancestor," 16116.

potential energy of the proton (or hydrogen ion) gradient at its boundary by coupling the (thermodynamically favored) entrance of a proton into LUCA with the chemical reaction that generates ATP from ADP (adenosine diphosphate) and a phosphate group. Despite having an ATP Synthase, however, LUCA does *not* seem to have proteins that *generate* this proton ion gradient *itself*. Researchers infer that this "paradox" could be reconciled if LUCA lived in an environment that provided a proton gradient *in situ*.[34] In short, LUCA's "ability to use but not generate ion gradients all point to the same environment: alkaline hydrothermal vents."[35]

In contrast to black smoker vent systems,[36] alkaline hydrothermal vents are "off axis vents" in that they do not sit right on top of zones of tectonic activity but rather a few kilometers away. These vents are formed through a process called *serpentinization* in which water seeps deep into the ocean floor below sea level into the Earth**.** In doing so, water chemically transforms the particular kinds of rock it touches, turning subsurface ultra-mafic rocks (which have low silica content) such as olivine, into a new kind of rock called serpentinite. In addition to newly formed

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[34] Madeline C. Weiss et al., "The last universal common ancestor between ancient Earth chemistry and the onset of genetics," *PLOS Genetics* 14, no. 8 (2018): e1007518. https://doi.org/10.1371/journal.pgen.1007518

[35] Madeline C. Weiss et al., "The last universal common ancestor between ancient Earth chemistry," e1007518.

[36] Alkaline hydrothermal vents are less well-known than deep sea black smoker vents. The latter exist at the boundaries between tectonic plate boundaries of the Earth's upper crust and mantle are spreading apart from one another. Here, water comes into direct contact with magmatic chambers within the Earth and remerges in the ocean at temperatures that exceed 300°C, carrying within it large amounts of black sulfide minerals that create dynamic dark-colored plumes, which gives these vent systems their name. Though black smokers are indeed far-from-equilibrium systems, in contemporary origins research, they are generally not considered ideal sites for the emergence of life as organic molecules tend to degrade rather than further complexify at such extreme temperatures. Despite this, Williams et al. (2005) have proposed black smoker sites as a possible setting for the emergence of life by speculating on how clays could have acted as *primordial wombs* that shielded developing organic molecules from degrading. Williams et al., however, do not focus on the thermodynamics of these clay inorganic wombs in their hypothesis, which makes their conception of "womb" differ from my focus here.

serpentinite, serpentinization generates hydrogen gas (H_2) that is dissolved in an alkaline fluid. This reaction is exergonic (it releases heat), which results in the products of serpentinization to travel back up the surface of the Earth (at the bottom of the ocean). When these fluids flow back up to the ocean floor, a gradient is formed between the alkaline-rich H_2 bearing, relatively warm (90 to 100°C) exhaled water interfacing with the cooler, more acidic ocean water. This fluid gradient is continuously maintained in an alkaline vent system for the duration of its existence (which can extend up to 150,000 years). The first alkaline vent system occurred in 2000.[37] It was found deep in the Atlantic Ocean "about 2,300 miles east of Florida on the Mid-Atlantic Ridge, one of the world's largest undersea mountain ranges,"[38] and had massive implications for geochemically oriented origins of life research.

[37] Geochemist Michael J. Russell predicted the existence of alkaline vent systems as well as their relevance to the origins of life in the early 1990s. See Russell, Daniel, Hall, and Sherringham (1994). Russell's ideas were largely viewed as idiosyncratic until alkaline vent systems were discovered in the Atlantic Ocean. His work now is at the center of geochemically oriented origins of life research.

[38] Sandra Hines, "Lost City pumps life-essential chemicals at rates unseen at typical black smokers," University of Washington News, January 31, 2008, https://www.washington.edu/news/2008/01/31/lost-city-pumps-life-essential-chemicals-at-rates-unseen-at-typical-black-smokers/.

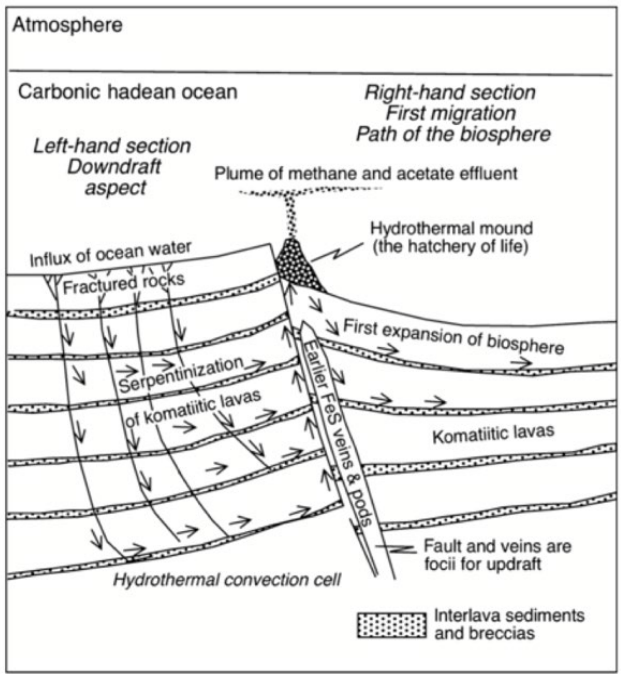

Figure 5: A schematic depiction of the process of serpentization (Martin & Russell, 2010)

One of the most remarkable things about alkaline vents is how the gradient between the "exhaled" alkaline, warm water interior and the cooler, more acidic oceanic exterior *mirrors* the chemical gradient that cellular life maintains at its boundaries against its exterior environment. While a fully evolved cell can maintain this chemically charged polarity itself through the ion pumps within its cellular membranes, the question of how this chemical gradient first arose in a world *before* the advent of genetics to code for pumps was an anomaly.

Given how the chemical gradient naturally formed in alkaline vent systems is similar to the chemical differentiation cellular life actively maintains within itself, how does a nonliving geochemical gradient evolve into a biochemical gradient of a cell? The answer lies in how the hydrological flow of water generates a chemical gradient as well as a physical compartmentation that is "semipermeable." Alkaline hydrothermal vents create the possibility for a living topology

not only because of the fluid gradient they create but also because of how they produce microscopic compartments or "inorganic pores." These microscopic "holes" are distinct from each other but still permeable to water and the movement of dissolved ions, especially tiny hydrogen ions (H^+).

While the modern-day alkaline vents found in 2000 consist of towering carbonate chimneys (which also have semipermeable compartmentation or womb-like properties), analogous vent systems on the early Earth would vastly differ in their chemical makeup. Four billion years ago, the ancient oceans were replete with dissolved iron (due to the lack of oxygen in the early atmosphere), making the alkaline vent systems generate iron sulfide (FeS) chimneys.[39] These microscopic iron sulphide holes provide the far-from-equilibrium semipermeable compartmentation necessary for cellular life to begin. Because of the constant movement of water and gradient between alkaline fluids meeting the ocean water, inside of these pores are hot H_2-rich alkaline fluids while the outside is much cooler and acidic. These pores are significant because they actually exhibit the polarity of modern cells which are also more alkaline in their interior. In other words, they *mime* the topology of living cells because of the gradient difference between inside and outside (see figure 6 below). An autonomous living cell, *once it is formed*, maintains this gradient on its own by microscopic pumps in its cell membrane (by actively pumping protons (H^+) out to keep itself alkaline on the inside).

[39] Martin and Russell, "On the origins of cells," 63.

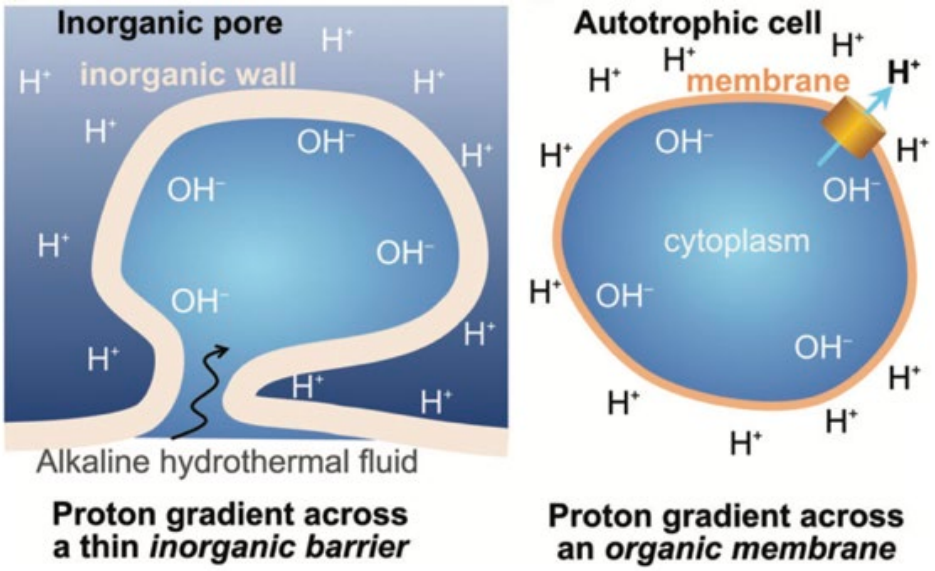

Figure 6: Proton Gradients across an inorganic barrier (left) and an organic membrane (right) (Sojo et. al, 2014)

To understand just how important cellular membranes are to life, we can turn to French philosopher Gilbert Simondon. In *L'Individu et sa genèse physico-biologique* (1995), Simondon argues that it is the membrane that constitutes the living being *qua* living. Simondon's ideas on the polarity of the membrane are strangely timely in that they put him directly in conversation with the argument that principle of "semipermeable compartmentation" needs to be addressed and actively theorized in life's origins. The significance Simondon places on the membrane has strong parallels in a certain strand within origins of life research that is geologically and geochemically informed (i.e. hydrothermal vent theories). Both stress how vital the *membrane*, or "semipermeable compartmentation," is to life.

Simondon and geochemically rooted origins research both take seriously the particular topology of life. The laboratory synthesis of urea in 1828 by Wöhler is often regarded as the experiment that shattered the doctrine of vitalism (i.e., the idea that there is an immaterial force

that fundamentally differentiates life from matter). By synthesizing a chemical associated with biological processes, Wöhler's success proved that living matter is not different in composition from inert matter and that the chemical components of life can be synthesized *in vitro*. According to Simondon, this focus of the "fabrication of living matter from inert matter" continues to motivate how one understands the relation between matter and life.[40] He reminds us that the synthesis of urea does not address the qualities most central to life and its difference from matter. If this is the case, the laboratory synthesis of chemicals found in the living body are not the answer. He draws attention to the specificity of the living:

> Until now, the problem of the ratios of inert matter and life has been centered around the problem of the manufacture of living matter from inert matter: it is in the chemical composition of living substances that the properties of life have been placed; since the synthesis of urea, many bodies of synthesis have been elaborated;…However, there is still a gap between the production of the substances used by life and the production of life [itself]: [to bridge this gap] it would be necessary to produce the topology of the living, its particular type of space, the relation between an environment of interiority and a milieu…The bodies of organic chemistry do not bring with them a topology different from that of the usual physical and energetic relations. Yet the topological condition is perhaps paramount in the living qua living. Nothing proves to us that we can adequately think of the living through Euclidean relations. The living space may not be a Euclidean space; the living being can be considered in Euclidean space, where it is defined as a body among bodies; the very structure of the living can be described in Euclidean terms. But nothing proves to us that this description is adequate. If there were a set of topological configurations necessary for life, untranslatable in Euclidean terms, one should consider any attempt to make a living with matter elaborated by organic chemistry as insufficient: the essence of the living may be a certain topological arrangement that cannot be known from physics and chemistry, which utilize in general a Euclidean space.[41]

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[40] Gilbert Simondon, *L'individuation à la lumiere des notions de forme et d'information* (Grenoble: Jérôme Millon, [2005] 2013), 223.
[41] Simondon, *L'individuation,* 223-4.

Euclidean space is a homogenous space "whose infinite divisibility makes possible the point-like localization of material particles."[42] The infinite divisibility and homogeneity of Euclidean space suggest that a spatial point exists in an external relation to another point in this kind of space. Simondon's incisive point here of the significance of the membrane finds a theoretical ally in 2016 article, "The Origin of Life in Alkaline Hydrothermal Vents." The authors write:

> What has been largely missing from experimental work on the origin of life over the last 70 years is much insight from life itself…Prebiotic chemistry has been approached from the intellectual tradition of synthetic chemistry, and the apotheosis is the ''one-pot synthesis''…But cells are not simply a pot of chemicals; they have a structure in space. Biochemistry is vectorial…meaning that reactions have a direction in space, frequently in relation to structures such as membranes.[43]

Simondon and origins research both take the constitution of the membrane seriously. In other words, origins of life theories (especially those that are not gene-centric) understand that the topology of life, especially its initial creation, is critical to address in a theory of life's origins. If the membrane makes the living being alive at every moment, what generated this capacity of re-polarization itself? Following Simondon, one could say that living individuation, in its first phase of individuation, is rooted within physical individuation in a very particular way.

Simondon also argues, "For the organism, the characteristic polarity of life is at the level of the membrane; it is here that life essentially exists as an aspect of a dynamic topology which *itself* maintains the metastability by which it exists. Life is self-maintaining metastability, but a metastability that requires a topological condition: structure and function are linked, because the most primitive and deepest vital structure is topological."[44] Simondon is right to say that life is

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[42] Milič Čapek, "Bergson's Theory of Matter and Modern Physics," in *Bergson and The Evolution of Physics*, ed. P.A.Y Gunter (Knoxville: University of Tennessee Press), 306.
[43] Sojo et al., "The Origin of Life in Alkaline Hydrothermal Vents," *Astrobiology* 2016 16(2): 182, emphasis mine.
[44] Simondon, *L'individuation,* 225-6, emphasis added.

engendered by a dynamic topology which maintains the metastability by which it exists. *Origins of life theories rooted in the Earth agree but* argue that the environmental and energetic needed to generate the topology of the living at the origins of life some 4 billion years ago already *had possessed a kind of proto dynamic topology* that marks life.

Returning to how archaea and bacteria have different membrane compositions but universal membrane bioenergetics, this strange difference makes sense if one takes into account that the last common universal ancestor out of which they both arose *already had a redox and chemical gradient* that was established through the movement and friction between two different fluid flows. In simpler terms, the first form of life, LUCA, derived its proto-semipermeability by depending "on natural proton gradients"[45] for the energy needed to drive carbon metabolism (the chemical changing of inorganic carbon such as CO_2 into organic carbon such as CH_4) in its ancient protein pumps. The shift from a direct dependence on proton gradients to autonomous cellular existence (autonomous in the sense of re-generating this gradient between inside and out *oneself*) in the distinct lineages of archaea and bacteria resulted in different membrane phospholipids and ion pumps *that enabled them to ceaselessly* (re)create a chemical and topological gradient between self and other.

These insights from contemporary research directly affirm Simondon's thoughts on vital individuation. If one of the distinguishing differences between physical individuation and vital individuation is the dynamic topology of the living—something noted by both Simondon and contemporary origins researchers—it is in these pores (or, to use more Irigarayan terminology, within these wombs) that the ontogenesis of vital individuation can begin. Though he generally

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[45] Nick Lane and William Martin, "The Origin of Membrane Bioenergetics," *Cell* 151, no. 7 (2012): 1407, https://doi.org/10.1016/j.cell.2012.11.050.

theorizes physical and vital individuation as two separate phenomena, there is a moment in Simondon's writings where physical individuation opens the possibility for living individuation to commence. He writes:

> It is habitual to see in vital processes a greater complexity than in non-vital, physico-chemical, processes. However, to be faithful, even in the most hypothetical conjectures, to the intention animating this research, we should suppose that vital individuation does *not* come *after* physico-chemical individuation, but during this individuation, *before* its completion, by suspending it at the moment when it has not attained its stable equilibrium, and by rendering it capable of extending itself and propagating itself before the iteration of a perfect structure capable only of repeating itself, [all these actions being] that which conserves in the living individual something of the pre-individual tension, of the active communication, in the form of internal resonance, between the extreme orders of magnitude.
>
> In this manner of seeing things, vital individuation would come to insert itself in physical individuation in suspending its course, in slowing it down, in rendering it capable of propagation in an inchoate state. The living individual would be in some manner, at its most primitive levels [*niveaux*], a crystal in the state of being born [*à l'état naissant*], amplifying itself without stabilizing itself.[46]

In this remarkable passage, vital individuation, at its origin, is not a difference in kind from physical individuation. In vital individuation, the metastability (still rife with potential) necessary for the propagation is maintained, slowed down (in the sense of not going to stable equilibrium) and somehow even amplified. This "amplification without stabilization" of vital individuation is possible when and where the metastability of the system that will individuate into a living being is rife with potential but *also* in *continual movement*. Returning to alkaline sea vents, it is in these sites that an opening in physical individuation can engender living individuation. The resolution of the physical individuation is kept open, *amplified without stabilizing*, thereby unfolding vital individuation. As I will detail in the following section, *iron sulphide wombs* generated from the hydrothermal exhalation of metallic and sulfide rich waters were *semipermeable compartments*

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[46] Simondon, *L'individuation*, 152, emphasis added.

that provided the conditions for cellular membranes to emerge.[47] If living individuation is not different in kind from physical individuation, the topology of a hydrothermal vent closes the gap for this new order of individuation to come into being. Thus, iron sulphide pores, as well as the continuous laminar flow of alkaline vent water creating a gradient with acidic cooler ocean water, are the theoretical, chemical, and physical seeds for vital individuation to "insert itself" into physical individuation, thereby sustaining the dynamic topology that marks cellular membranes.

2.2 Semipermeable Compartmentation, or, The Hydro-logics of Iron Sulphide Wombs

> "*The Biological Sciences* have been slow to take on certain problems. The constitution of the placenta tissue, the permeability of membranes, for example. Are these not questions directly correlated to the female and maternal sexual imaginary?"
>
> —Luce Irigaray, *An Ethics of Sexual Difference*[48]

Geochemically rooted origins of life research argues that life's beginning required something *other than* stable equilibrium. In geochemical terms, "equilibrium is death."[49] If the chemical processes that mark extant life require nonequilibrium, then perhaps those that brought it into being do as well: "the question remains of how a solution at equilibrium can start doing chemistry. Put another way, once auto-claved, a bowl of chicken soup left at any temperature will never bring forth life."[50] A prebiotic soup stockpiled with ingredients, even if it is heated, cannot generate life. Geochemistry *becomes* biochemistry when chemical disequilibrium operates in tandem with the hydro-logics of a womb.

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[47] Martin, "On the origin of Cells," 65.
[48] Irigaray, *An Ethics of Sexual Difference*, 123.
[49] Sojo, Pomiankowski, and Lane, "A Bioenergetic Basis for Membrane Divergence," e1001926.
[50] William Martin and Michael J. Russell, "On the origins of cells," 62.

According to Irigaray, the unconscious of science affects "the research goals that science sets, or fails to set for itself."[51] The seeming neutrality of the subject of science becomes evident if one pays attention to how certain questions and topics are continually elided and ignored within an avenue of research. The constitution of the placenta tissue, though it is also a profound mediating relation, refers to mammalian animal gestationality. Because it is a much later evolutionary event after the initial emergence of single-cellular life, it is not my focus here. Instead, I will focus on origins research that, surprisingly agrees with and affirms Irigaray's contention that the "problem" of the *permeability of membranes* has not significantly been addressed in biology. I will track how the permeability of membranes directly concerns the maternal, extending all way back to the birth of cellularity. Though it is unlikely that they read her work, Irigaray's diagnosis of how the question of the membrane is constantly eschewed is echoed by two scientists, William Martin, a microbiologist, and Michael J. Russell, a geochemist, in an article that theorizes the origin of cells.

According to Martin and Russell, origins of life research over-focuses on concocting the "right mixture of self-replicating molecules."[52] A strict focus on the "right kind of stuff" makes the question of how that "stuff" was first enveloped in a membrane (the hallmark of all cellular life) recede out of focus. If genes code for membranes, Martin and Russell argue that the question of how the first replicating systems *encased themselves* (without needing something that encased them) is a concern that is consistently not addressed:

> Getting the universal ancestor into the membranous or other cloak that it has to have at some time under all models for the origin of life and the origin of cells poses seemingly insurmountable problems. In models for the origin of cells, the membranes that surround living systems—under whatever chemical premise and if they are addressed at all—just

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[51] Irigaray, *An Ethics of Sexual Difference*, 122.
[52] Martin and Russell, "On the origins of cells," 63.

> seem to come from thin air, and the ultimate contents of cells so derived have to arise as a free-living cytosol that needs to get inside, even in well-argued cases.[53]

The second-class status of the "membrane problem" in this epistemological framework is directly at odds with the actual evolution of life. The authors seek to rectify a glaring issue in origins research that has been created through an overwhelming focus on the origins of genetics and code, which often results in ignoring how membranes and their permeability first arose and thus overlooks a fundamental feature of life: the principle of semi-permeable compartmentation. Martin and Russell state that **"**the principle of semi-permeable compartmentation from the aqueous environment is even more strictly conserved than the universal genetic code, because there are rare deviations from the universal code."[54]

One reason semi-permeable compartmentalization, or more concisely, a *womb*, is a requirement of life is that it directly addresses what is known as the "concentration problem" in origins research: how did the pre-organic precursors of life remain in close enough proximity to further react and complexify in the ancient Hadean ocean?[55] Without any boundary, these precursors would have diffused far away from one another in the ancient expansive ocean, most likely never to chemically react again. In the middle of the last century, the idea of "surface catalysis," in which certain inorganic compounds such as clay, rocks, and metals provide a catalytic *surface* for prebiotic reactions to occur upon, attempted to address the concentration

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[53] Martin and Russell, "On the origins of cells," 63.
[54] Martin and Russell, "On the origins of cells," 63. Martin and Russell are aware that viruses complicate the "principle of semi-permeable compartmentation." This is not a theoretical oversight, however, but rather an intentional exclusion. This is because although viruses do destabilize the concept of life, they still require semi-permeable compartmentalization: viruses depend upon cellular forms of life that *are* bounded and semi-permeable to replicate. On how viruses complicate the concept of life, see Dahiya (2018).
[55] Christian De Duve (1991) coined the concentration problem.

problem.[56] Simply providing an energetic surface for prebiotic reactions to occur, however, is not enough: "a fundamental drawback to the surface catalysis model is that once two molecules have reacted on a surface, they diffuse away into the Hadean ocean, never to react again."[57] Over and above simply a surface, spatio-temporal structures that have specific forms of interiority and semipermeability are crucial. For researchers such as Martin and Russell, "containment"—a "dead" characteristic often associated with the "feminine"—was a fundamental requirement for the emergence of cellular life.

The semipermeable compartmentation that primordial wombs could provide in emergence of cellular life is not solely an enclosed space where the precursors of life can continually react and complexify. The material enclosures Martin and Russell spotlight also provide a far-from-equilibrium geological milieu that strangely parallels extant cellular life in terms of the temperature, pH, and ion gradients they generate. Semipermeable containment and bioenergetic chemistry are fundamentally interlinked: *the beginning* of *membrane chemistry requires a boundary.* Any possibility of a resolution of this problem can only appear if one first thinks through the realities of unicellular membranes themselves.

If the beginnings of cellular life coincide with the invention of biochemistry, the differences between inorganic chemistry and biochemistry are such that the latter can emerge if it is "coupled to an external disequilibrium"[58] that can drive the reactions of life. The specific kind of geochemical disequilibria found at alkaline hydrothermal systems generates an "'abiotic'

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[56] Günter Wächtershäuser (1988) is the primary advocate of surface catalysis.
[57] Martin and Russell, "On the origins of cells," 62.
[58] Elbert Branscomb and Michael J. Russell, "Frankenstein or a Submarine Alkaline Vent: Who is Responsible for Abiogenesis? Part 1: What is life–that it might create itself?" *Bioessays* 40 (2018): 1700179.

womb."[59] In a speculative theoretical piece on submarine alkaline vents, Russell and Elbert Branscomb, a theoretical physicist, theorize that

> Perhaps it was literally the deep bosom of the ocean whose coddling Hadean embrace and uniquely fecund far-from-equilibrium geophysical distempers 'transcended' chemistry in exactly the required biological ways and thereby leapt the key initial barrier to giving birth to life (and thoughtfully did so in a womb safely tucked away from, amongst other things, the especially ruinous horrors of the Hadean's UV radiation [that bombarded the surface of the early Earth]).[60]

These "dissipative processes that indirectly produce chemically specific, pro-biological, 'trans-membrane' gradients of both redox and ion-concentration types" makes them "the [thermodynamic] drivers of life's emergence."[61] In this origins scenario, iron sulphide wombs generated from the hydrothermal exhalation of metallic and sulfide rich waters are *semipermeable compartments that preexist membranes, and in doing so, create the possibility of their existence by providing (porous) boundaries and disequilibria that can drive the reactions of life necessary for the birth of biochemistry into being.*[62] If life, in its initial cellular emergence, is not different in kind from far-from-equilibrium matter, the gestational space of alkaline vents closes the gap for this "embryological" unfolding.

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[59] It is interesting to note here that Branscomb and Russell place scare quotes around *abiotic* and not womb. This rhetorical emphasis is different from how "primordial womb" in scare quotes in Williams et al. (2005). I read this as Branscomb and Russell striving to expand the concept of womb, making it precede the beginnings of cellular life, while also simultaneously complicating the boundary between "biotic" and "abiotic."

[60] Branscomb and Russell, "Frankenstein or a Submarine Alkaline Vent: Who is Responsible for Abiogenesis? Part 2: As life is now, so it must have been in the beginning," *BioEssays* 40 (2018): 1700182.

[61] Branscomb and Russell, "Frankenstein or a Submarine Alkaline Vent: Part 2," *BioEssays* 40 (2018): 1700182.

[62] Martin and Russell, "On the origin of Cells," 65.

Figure 7: (a), (b) and (c) successively enlarged images of a 360-million-year-old FeS chimneys. d) laboratory created FeS compartments (Martin and Russell, 2003)

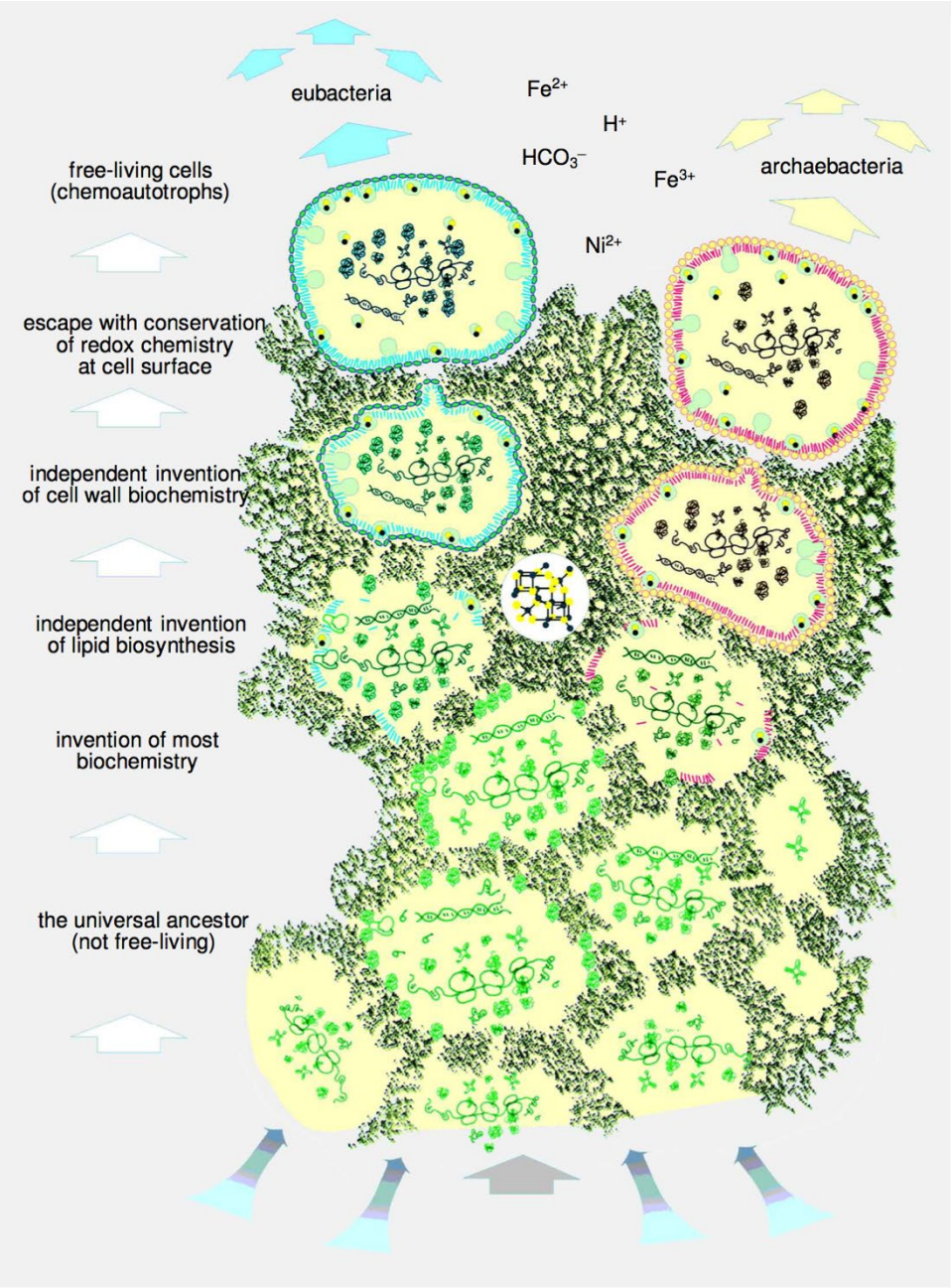

Figure 8: Theorizing evolutionary divergence archaea and bacteria from the last universal common ancestor (Martin and Russell, 2003)

2.3 Conclusion: What Life Shares with Matter

For Luce Irigaray, "[a]n ethics of sexuate and sexual difference is the basis of an ecological ethics."[63] In her essay "Starting from Ourselves as Living Beings," Irigaray outlines how dominant Western, Eurocentrically derived forms of language regarding life "bears witness to an intention of mastering" rather than "a desire to coexist with respect for the differences between" living beings.[64] This impulse for mastery rather than coexistence that respects the sexuate alterity of the other manifests in the words we have to comprehend life:

> We really have not a lot of words to express a coexistence in life itself…We lack words to express this universal sharing between us, a sharing that unites us on this side and beyond every definite culture, civilization, and even species, and the expression of which would be crucial to achieving an ecological ethics. All the living beings are more interrelated, whatever their difference(s), than our discourses let us assume, a deficiency which does not contribute toward the respect for our common belonging and for the environment that is necessary to it.[65]

This chapter extends Irigaray's grounding of an ecological ethics generated from a philosophy of sexuate difference by theorizing the emergence of life from matter between 4.4 and 3.8 billion years ago[66] If "our" (biological) discourse hides what all life shares, then in the spirit of Irigaray, I hope to remind us what all life shares at its origins: the debt it owes to a maternal milieu that preexisted and conditioned the possibility of its emergence. In the geochemically rooted origins research I have highlighted above, the emergence of cellular life becomes a highly probable statistical inevitability rather than an improbable occurrence. This rhetorical transformation signals an epistemological and ontological reframing of the relation between matter and life. At

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[63] Luce Irigaray interviewed by Emily Anne Parker, "Interview: Cultivating a Living Belonging," *Journal of the British Society for Phenomenology* 46, no. 2 (2015): 111.
[64] Irigaray, "Starting from Ourselves as Living Beings," *Journal of the British Society for Phenomenology* 46 (2015): 106.
[65] Irigaray, "Starting from Ourselves as Living Beings," 106–7.
[66] Martin and Russell, "On the origins of cells," 60.

the origins of cellular life, the relation between matter and life shifts from a difference in kind to one of degree. The hydro-logics of primordial inorganic wombs engender these rhetorical, epistemological, and ontological shifts, thus offering us a way to fundamentally reorient how we understand the nature of life and its capacity to be engendered by, and to further generate, difference.

Origins research that thinks in tandem with the logic of a womb and a non-anthropomorphic concept of the "maternal" brings us closer to understanding one of the most pressing and enduring questions we, as human beings, have been asking about our origins. For Irigaray, to "live maternity" necessitates being "capable of engendering the living endowed with autonomous existence with respect to them."[67] The theoretical absence of research about the first cell membranes confirms Irigaray's assertion that the biological sciences have been negligent on the question of their permeability. The particular kind of matter that characterizes primordial wombs cannot be easily classified as purely "living" or "nonliving" but rather operates in an interval between these two. Irigaray's inkling that the permeability of membranes needs to be a serious question within biological research carries more weight than perhaps she herself was aware. Theories of life's origin that resonate with an Irigarayan philosophy of life understand embodiment as an irrefutable feature for the emergence of cellular life. This cellular interiority is a fluid body in which the first forms of life gestated. The constitution of interiority—of a defined yet permeable boundary between self and other, inside and outside—was not an afterthought in the origins of cellular life but rather was part and parcel of life's emergence from matter. The geochemical disequilibria of these gestational semipermeable spaces provided the conditions for the possibility of life to begin, to germinate until it could maintain the complex thermodynamic

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[67] Irigaray, *Conversations*, 7.

conditions itself. The emergence of life is not possible with a "spark of life" running through a passive, fluid oceanic milieu. This model, in which an outside "active" other, a force bringing life (through light), is actually too thermodynamically weak to explain the complex bioenergetics that are needed to drive the dissipatory structures that can *then* engender the disequilibria that we term "life."

3. Engines of Creation: Protometabolism and A Logic of At least Two

3.1 Feminism and Metabolism: Energy versus Disequilibrium

We typically think that we eat food so that we can have energy to function. This idea encompasses how we understand metabolism as a process that unleashes *energy* within food. In its most basic biological definition, metabolism refers to the entire set of chemical reactions that occur in a cell.[1] These metabolic activities are what keep us alive. A fully functional metabolism seamlessly integrates a range of cellular processes into one organismic whole. While it is possible to understand an already functioning metabolism by separating it into a series of different reactions or steps, the complex interconnections between these chemical circuits make it impossible to contemplate the origins of metabolism itself, especially using a step-by-step manner. In this chapter, I argue that a feminist philosophy of life would be able to account for the *emergence* of metabolism itself, rather than just simply address a mature metabolism already in circuit. In order to accomplish this aim, I focus on how metabolism has been taken up within feminist theory, as well as in origins research investigating the beginnings of metabolism.

I begin by outlining how metabolism can be understood through two approaches: equilibrium thermodynamics and *non*equilibrium thermodynamics. The former theorizes

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[1] A more detailed definition of metabolism "is the sum total of all the biochemical reactions taking place within a cell. It includes all the reactions involved in degrading food molecules, in synthesizing macromolecules needed by the cell, and in generating small precursor molecules, such as some amino acids, for cellular needs. It also includes all reactions involving electron transfers (oxidation–reduction, or redox, reactions). Metabolism takes place in sequences of biochemical reactions called pathways" (David W. Tapley, "Metabolism, Cellular." In *Biology, 2nd ed*., edited by Melissa Sue Hill, 74-77. Vol. 3. Farmington Hills, MI: Macmillan Reference USA, 2016. Gale In Context: Science (accessed February 12, 2020). https://link.gale.com/apps/doc/CX3629800273/SCIC?u=duke_perkins&sid=SCIC&xid=992f95ec.).

metabolism through the concept of *energy* (as an external source injected into a system), and analyzes metabolism as a series of discrete states, while the latter understands metabolism as a series of processes that are born out of—and, once born, maintain themselves through—the dissipation of disequilibrium. I contend that a feminist philosophy of life would *not* understand metabolism through equilibrium thermodynamics because this framework is *in*capable of theorizing the beginnings of proto-metabolism itself (which, again, would be the litmus test for a such a philosophy). Metabolism, at its most fundamental level, *is about the flow of entropy or disequilibrium rather than energy*, and should therefore be theorized using nonequilibrium thermodynamics.

This chapter challenges the idea that "energy" can explain metabolism, or that organisms such as humans eat to "unleash" energy in food. It does so using scientific research that argues the role of entropy has been grossly misunderstood in the emergence of life, and that entropy, rather than energy, is metabolism's condition of emergence. Specifically, I examine how a non-anthropocentric conceptualization of a logic of sexual difference opens up the possibility of understanding the emergence of metabolism. If sexual difference explodes any and all notions of "oneness" as the conditions of thought and the natural world, this chapter speculates on how a logic of *at least two* can help generate a novel way of understanding the relation between entropy and order in relation to metabolism. I do this through a consideration of Elizabeth Grosz's concept of sexual difference as an *engine of creation* and life itself, and juxtapose Grosz's conceptualization of sexual difference with Myra J. Hird's thesis that sexual difference is too rigid for feminist ontology, and that metabolism, over and above sexual difference, can generate such an ontology. According to Hird, metabolism may collapse the life/nonlife bifurcation.

While I agree that metabolism does cut across the separation of life from nonlife, I argue that Hird's theorization of metabolism is rooted in equilibrium thermodynamics, which relies on a

binary relationship between nonlife and life, and because of this, is unable to account for the emergence of (proto)metabolism itself. In contrast to Hird, I contend that nonequilibrium thermodynamics is a theoretically ally of sexual difference—especially if one considers Grosz's idea that sexual difference is *an engine* of life. I use this idea to think with far-from-equilibrium origins research that argues the question of how life emerged as an orderly state can be reimagined through a reformulation of the concept of entropy as a *maternal* engine. This reimagining of entropy as a maternal engine that seeks to dissipate itself allows for less-probable reactions to be "driven" in existence, including the proto-metabolic reactions necessary for organismic closure. Though the idea of "maternal engine" is a metaphor, the logic it elaborates—a logic of at least two—is the logic of the real. I use this logic of at least two to theorize a new concept of machine that reframes how we can understand the origins of enzymes, proteins that are biological catalysts at the heart of cellular metabolism.

3.2 The Engine of Life

While there is a resounding interest in contemporary feminist theory to reframe the human's relation to the natural world and the nonhuman, the manner in which this aim is undertaken is not uniform. One scholar who has extensively focused on the non-human in feminist theory through a microscopic and bacterial frame is Myra J. Hird.[2] In her essay "Digesting Difference: Metabolism and the Question of Sexual Difference," Hird experiments with the idea of "ontology of metabolic difference" for a feminist engagement with Nature.[3]

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[2] See, for example, Hird's *The Origins of Sociable Life* (2009) and *Sex, Gender, and Science* (2005), as well as a special issue she co-edited with Celia Roberts on "Feminism theorises the nonhuman" in *Feminist Theory* 12, no. 2 (2011): 109-117.
[3] Hird, "Digesting Difference: Metabolism and the Question of Sexual Difference," *Configurations* 20 (2013): 216.

Taking up Elizabeth Grosz's reworking of Darwinian evolutionary theory using Irigaray's philosophy of sexual difference, Hird specifically aims to critique Grosz's bringing together of sexual difference with evolutionary theory through the "argument for sexual difference as ontology."[4] Hird argues that metabolism can and should displace sexual difference as the bedrock of feminist engagements with evolution because the former is a more capacious ontological mode of *being* than sexual difference. Sexual difference is too narrow and derivative a category for Hird; a feminist ontology rooted in *metabolism* and evolutionary theory would be more encompassing and generative than sexual difference. Hird directs her attention to Grosz's argument that

> "[w]ithout sexual difference there may be life, life of the bacterial kind, life that reproduces itself as the same except for contingency or random accident, except for transcription errors at the genetic level, but there can be no newness, no inherent direction to the future and the unknown." Sexual difference, writes Grosz, "erupts massive variation and difference into the world of the living; it is a difference machine that ensures all progeny vary from their parents, and that all individuals differ from each other (with the exception of identical twins)."[5]

According to Hird, evolutionary theory rooted in an ontology of sexual difference produces a series of contradictions.[6] She takes issue with Grosz's suggestion that without sexual difference there would only be bacterial life—life that the latter understands as lacking ingenuity and difference. Hird argues that this is a humanist reading of sexual difference that ignores how most of life on Earth is not sexually dimorphic in addition to being contradictory to Grosz's aim to displace the centrality of the Human. For Hird, Grosz collapses sex with reproduction and thus ignores the separation of these two phenomena in the microbial world. Furthermore, she argues that Grosz's privileging of sexual differences risks reproducing gene-centric approaches to

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[4] Hird, "Digesting Difference," 213.
[5] Hird, "Digesting Difference," 227, citing Grosz, *Becoming Undone,* 133.
[6] Hird, "Digesting Difference," 223.

evolution because it understands difference to erupt only at conception and not at any other subsequent point during an organism's lifetime (a mistake, Hird contends, that would not arise if one were to adopt a metabolic microbial perspective).

Sexual difference, according to Hird, operates through "the assumption that organisms are bounded and at least semi-autonomous individuals," a fiction that ignores an entangled and symbiotic perspective of life rooted in contagion we find in deep time:

> from a deep-time perspective, nonsexually reproducing organisms like bacteria have infected, affiliated, formed and entangled webs, and produce much more novelty than all other kinds of organisms put together. Bacteria, in other words, have engendered newness, difference, and creativity like no others. Clearly, evolution does not require sexual difference as a prerequisite for newness, novelty, or generation.[7]

Hird uses biological research that attests to the formative role bacteria have had in the evolution of life (as well as the evolution of difference) to undermine Grosz's thesis that bacterial life, as life "without sexual difference," is devoid of novelty. She reminds us that most of life's evolutionary history did not utilize sexual reproduction yet still generated difference. In short, Hird understands sexual difference as too static a formation to be evolutionarily useful or proliferative. In response to this limitation, she experiments with introducing metabolism *as a foil* to sexual difference. Hird writes:

> To work my way through the complex questions that an ontology of sexual difference invites, I introduce metabolism as sexual difference's foil. Metabolism, including intake, digestion, and transport, is a primary and defining feature of life and an activity that all life forms, from cells to whole organisms, must engage in to maintain themselves. *Metabolism, I will argue, may even be deployed to collapse the life/nonlife bifurcation*. Given its immanence to the origins of life on Earth and its centrality to *all* life, we might propose *metabolism as ontology*—an "ontology of metabolic difference" if you will. In other words, perhaps a substitution is in order: namely, metabolism *for* sexual difference. Instead, I want to think through the advantages of understanding metabolism as an

[7] Hird, "Digesting Difference," 229.

> evolutionary force; that is, metabolizing as a force of evolution and an inorganic activity through which cells, organisms, life, and nonlife maintains, develops, and responds.[8]

Appropriating a key concept from *Becoming Undone* that sexual difference is an *engine* or motor of life,[9] Hird argues that instead of sexual difference, metabolism is "quite literally, the 'engine of life,' as Grosz puts it."[10] In this chapter, I explore the conceptual thread that metabolism straddles the line between non/living and living, and how, therefore, it might inform feminist engagements with biology as a whole. Rather than a close reading of Hird's framing of Grosz, I argue that while Hird intuits the conceptual richness of fertility and self-maintenance, the opposition she stages between metabolism and sexual difference, and her subsequent privileging of the former, rests on a false dichotomy between the two terms. Though Hird is invested in thinking with/in a philosophy of becoming, she is unable to understand sexual difference outside of the sexed (that is, the bodily morphological) effects it produces. In short, Hird misreads and conflates the philosophy of sexuate difference with bodily morphologies. (Furthermore, I sense that Hird understands bodily morphologies as static.[11]) For Hird, sexual difference is synonymous with the bodies that are actually the effects of this engine, not the engine itself.

If metabolism is a primordial process that straddles the boundary between nonliving and living, the question of *how* a proto-metabolism *itself* was engendered must be addressed in a

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[8] Hird, "Digesting Difference," 216, emphasis added.
[9] Grosz, *Becoming Undone*, 103.
[10] Hird, "Digesting Difference," 236.
[11] For Hird, sexual difference is an ontology of stasis, and for this reason should not ground a feminist engagement with evolution. Instead of sexual difference as a framework, Hird suggests "that engaging different refractions of evolutionary theory may lead to yet other openings for feminist theory...[central to this] analysis is a move away from an ontology based on an understanding of natural selection as both generative of difference that, once generated, *maintains stasis* (of form, organization, ontogeny, and so on) and describes the dominant way in which difference is generated (generates itself)" (Hird, "Digesting Difference," 215-6.).

feminist philosophy of life. Hird does not address the origins of metabolism, in other words, the conditions of its emergence. This, to me, is a useful oversight that allows her to bypass theoretical concerns that might undermine her thesis. If metabolism straddles the distinction between nonlife and life, how does metabolism itself come into being? Hird is able to *avoid the question of emergence* by rushing over the origins of cellular life itself and by focusing on (already formed) prokaryotic bacteria up to eukaryotic life-forms. By only thinking from single-cellular life once *it has already emerged*, Hird bypasses the question of sexual difference as *an engine* altogether.

Though Hird's reliance on metabolism as an evolutionary force is heading in a provocative direction, two issues arise here. The first, as mentioned earlier, is how the lack of attention to how *metabolism itself was driven into being* covers over a vastly important question. Second, Hird's understanding of metabolism is rooted in equilibrium thermodynamics and is therefore at odds with more interesting (and accurate) readings of metabolism that *non*equilibrium thermodynamics can produce, ones that harbor the potential to radically reorient how we understand not only metabolism but life itself. These two problems are related. Metabolic thinking that is paradoxically rooted in equilibria is pervasive in biology. What I mean by this is that there is a tendency to understand metabolism as a series of discrete states that move from one state to the other through the external injection of energy. This understanding of metabolism falls under the rubric of classical equilibrium thermodynamics, which limits itself "to the consideration of equilibrium states or to states only incrementally or 'quasi-statistically' displaced from

them."[12] This is to say that metabolism as it is understood through classical thermodynamics is inherently *non*-dynamic.[13]

In contrast to Hird's implicit reliance on an equilibrial framework, I argue that a feminist philosophy of life would understand metabolism instead through *non*equilibrium thermodynamics. This is because such a philosophy would be adept at theorizing the beginnings of proto-metabolism itself, and this can only be done using nonequilibrium thermodynamics. Like Hird, a feminist rendering of metabolism would recognize how metabolism cuts across nonliving and living but then also be able to explain how such a process itself came about. It is the wager of this chapter (and this project more broadly) that a feminist philosophy of life would unfold the logic of Nature itself. Thus, a scientific framework that more accurately represents a natural process such as metabolism would be an ally to such a philosophy.

In lieu of construing metabolism as a foil for sexual difference, in this chapter, I explore how sexual difference is an engine of life, and how this engine can generate a theory about the origins of metabolism. I argue that sexual difference as an engine can account for the *beginnings* of proto-metabolism, which is the litmus test for a feminist philosophy of life. If sexual difference, at base, addresses how neither philosophy nor reality can be adequately thought on a logic of the "one," below I demonstrate how a metabolism rooted in a *logic* of sexual difference, that is, a logic of *at least two* processes, coincides with a radical rethinking of the nature of energy and entropy by some scientists studying the origins of metabolism, and how this in turn opens up a theory of how metabolism itself came into being.

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[12] Elbert Branscomb and Michael J. Russell, "Turnstiles and Bifurcators: The Disequilibrium Converting Engines that Put Metabolism on the Road," *Biochimica et Biophysica Acta* 1827 (2013): 63.
[13] Branscomb and Russell, "Turnstiles and Bifurcators," 63.

In contrast to Hird using metabolism as a foil to sexual difference, I delve into the concept of engine in relation to sexual difference, and how *such* an engine can account for the beginnings of metabolism. On this Elizabeth Grosz writes,

> [s]exual difference is the difference which 'is not one'; it is a mysterious force of creativity, indeed the very measure of creativity itself…. Sexual difference is the very machinery, the engine, of living difference, the mechanism of variation, the generator of the new. Sexual difference ensures that each generation and each individual is unique, irreplaceable, new, historically specific, different from all others, and able to be marked in relation to others….The forgetting of sexual difference is the ''dereliction in our time'' (to borrow a phrase from Irigaray), the forgetting of the conditions of life itself, and thus a kind of (atomic) imperiling of life from within, an inherent self-destructiveness in a life that does not admit its own complexity and entwinement with otherness.[14]

Metabolism and sexual difference are not in conflict if sexual difference is fully theorized as an engine—that is, as an ongoing and dynamic process of production. As I understand it, sexual difference is an engine that abides by and creates through a logic of at least two. Sexual difference, in this sense, avoids the risks of being anthropocentric, and thus avoids Hird's central critique of Grosz's claim that sexual difference does not operate in and across bacterial life. Hird's deployment of *metabolism* as the *engine of life* is unfortunately still rooted in stasis, which becomes evident in how the origins of metabolism itself is not only missing from her analysis, but something her framework fundamentally cannot address.

My interest in sexual difference as an engine (one that, moreover, can produce sexually differentiated bodies but should not be conflated with them) that unfolds through a logic of *at least* two stages the possibility for engaging with origins research that theorizes the birth of metabolism. In the contemporary origins of life research I focus on below, the birth of metabolism is theorized through the language of "maternal" engines of creation. The concept of an engine, as well as a rethinking of entropy and energy, is necessary for working towards a

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[14] Elizabeth Grosz, *Becoming Undone*, 101-2, emphasis added.

theory of metabolism that does not begin with cellular bodies that are already formed where the question of origins, and an allied feminist philosophy of life, is once again elided. To begin thinking of metabolism as a process produced by the engine of sexual difference, we can turn to how dissipation for Irigaray is a generative process outside the symbolic imaginary of phallocentrism, which is the imaginary of stasis.

3.3 Entropy, Disequilibrium, Dissipation

In *An Ethics of Sexual Difference*, Luce Irigaray experiments with whether the processes that would encompass "female sexuality" can be represented through a scientific model. Irigaray writes:

> If a scientific model is needed, female sexuality would perhaps fit better with what Prigogine calls 'dissipatory' structures, which function through exchanges with the exterior world, which proceed in steps from one energy level to another, and which are *not* organized to search for equilibrium but rather to cross thresholds, a procedure that corresponds to going beyond disorder or entropy without discharge.[15]

Like Irigaray in this passage, my interest is not to define and solidify female sexuality. Rather, I am interested in how the logic of "female sexuality" cannot be *adequately* thought through a logic of solids. A "dissipatory" structure instead would be a better model for female sexuality. This dissipatory structure, furthermore, desires to cross thresholds—it is not afraid or stumped by disorder. Furthermore, this scientific model or hypothesis of "female sexuality"—in how it moves beyond "entropy without discharge"—affirms the second law of thermodynamics. If, according to the second law, the entropy of the universe must always be increasing, in a spatially bounded yet permeable system, "it is only the irreversible processes taking place *within* the system [rather than the flow of matter/energy across and into the system] that affect the entropy of the universe."[16]

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[15] Irigaray, *An Ethics of Sexual Difference*, 124.
[16] Branscomb and Russell, "Turnstiles and Bifurcators," 64.

Such a "structure" can only be maintained by a continuous flux of energy. It therefore is contingent on *disequilibrium*.

Female sexuality could align with such a logic because it would never remain the same "one" thing, but would always be open to becoming more, something unknown, that could not be predicted in advance—in effect, a creative process that would embrace entropy and the arrow of time. Coined by Nobel Laureate Ilya Prigogine (in a paper written with Gregoire Nicolis) in 1967,[17] dissipative structures are non-equilibrial structures that "must necessarily 'feed' on fluxes of matter and/or energy (thus, on external constraints) that permanently maintain the system far from equilibrium. They can only exist in open systems."[18] A dissipatory structure is a particular spatiotemporal organizational state that arises within a dissipative process that is an open system exchanging energy and matter with its environment. "Dissipative structures are generated and maintained through irreversible processes that continuously generate entropy."[19]

When sexual difference is understood as a generative engine—in other words, when it is not conflated with already formed sexed bodies—it creates the possibility of metabolism itself, and once the latter has formed, can be thought of as the *activity* of metabolism as well. What I mean here is not a vague idea of "sexed" bodies operating in the origins of life. Rather, sexual difference is of relevance here as a concept because it argues that the world cannot be understood under the logic of oneness. In terms of complexity and self-organizing systems, a logic of one-ness correlates with linear thinking. If complexity must inherently address *non*-linearity, then

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[17] Ilya Prigogine and Grégoire Nicolis, "On symmetry-breaking instabilities in dissipative systems," *The Journal of Chemical Physics*, 46, no. 9 (1967): 3542-3550.
[18] Radu Balescu, "Ilya Prigogine: His Life, His Work," in *Advances in Chemical Physics: Special Volume in Memory of Ilya Prigogine*, Volume 135, ed. Stuart A. Rice (Wiley & Sons: Hoboken, NJ, 2007), 13.
[19] Dilip Kondepudi and Ilya Prigogine, *Modern Thermodynamics: From Heat Engines to Dissipative Structures*, 2nd ed. (Wiley: West Sussex, United Kingdom, 2014): 428.

complexity is always an irreducible interaction between two or more processes.[20] Here, the idea of an engine that generates order through the tension between two or more reactions becomes possible. The idea of metabolism being about energy transfer becomes untenable, since a self-organizing system does not produce order through consuming and transferring energy to move pre-existing parts.

Rather than a metabolism rooted in the consumption of energy, this process must instead be connected to the concept of disequilibrium. The necessity to theorize disequilibrium is at the center of geochemically rooted origins research. On this, two researchers write:

> *What precisely is a "disequilibrium"?* When a quantity of matter and/or energy ("M/E") can exist within a spatially bounded system in two alternative states (necessarily equal in all relevant conserved quantities) those states will form a disequilibrium (a "gradient") if and only if *they differ in their entropy content*. […] [A] disequilibrium is therefore fundamentally defined by the condition that the two alternative states differ in entropy content, i.e. in microstate multiplicity. […] Discussions of bioenergetics almost always have "energy" center stage and running the show—albeit energy suitably discounted (in "its ability to perform work") by the 2nd law tax. But this, in our view, is misleading. Energy *doesn't* drive processes—or become "consumed" or "used" in their occurrence. *Disequilibria (via their dissipation) alone are to blame for why—and how—things happen (and not just in the processes of life*); although it is true that much of the entropy difference that defines these disequilibria is due to differences in how the energy involved is 'packaged' or distributed; that is, while energy is typically a dominant contributor to the "medium", the "message" is disequilibrium dissipation and creation.[21]

When the second law of thermodynamics is rhetorically rendered as a tax, the authors imply that it is understood as a required nuisance that does not generate effects. In my view, metabolism needing disequilibria-generating engines reorients how life may arise as an orderly state. Disequilibria are rooted in an irreducible interaction between two or more "opposing" processes

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[20] I connect non-linearity to a logic of at least two because metabolism in the framework of nonequilibrium thermodynamics requires the precise coupling of two opposing processes. I outline this non-linear logic of at least two in detail in the latter part of the chapter.
[21] Branscomb and Russell, "Turnstiles and Bifurcators," 63, emphasis added.

in tension. Energy transfer, in contrast, is usually thought of in the singular—as a force that externally acts upon something to initiate change. Though this difference between theorizing disequilibria and energy may be ignored in an already formed biological body, it crucial to note that it cannot be discounted in the emergence of cellular life itself. This is because disequilibrium, not energy, provides the conditions for self-organization to occur. The possibility of the birth of a (proto)biological body becomes possible only through disequilibrium. One can understand the metabolism of an already formed biological body through energy, but energy cannot generate the conditions for self-organization to occur, precisely because energy transfer can explain the movement of already existing parts, but *not* the genesis of these *parts themselves*. Thus in an already formed body, one can understand metabolism as the movement of one discrete state to the next that relies on energy. This understanding is not scientifically accurate, but because the difficult task of the birth of the system has already occurred, equilibrial thinking can at least weakly account for a metabolism that is already in existence. Disequilibrium, by contrast, can explain the emergence of a biological body *as well its continuing metabolic activity.*

To reiterate my opening point, in everyday speech, we think that we consume food for energy—that our bodies unleash energy from within food to power themselves. The historical emergence of metabolism in origins of life research is still intensely being debated, and like other questions about the emergence of cellular life, something that can never fully be known. I argue here that the operations of metabolism—its logic—are misrepresented and misunderstood in biochemistry and biology and especially the subfield of bioenergetics. This misunderstanding is carried over and shared with how metabolism and energy are discussed in everyday life. If bioenergetics itself misunderstands its object of study, this moves us further away from theorizing how the first metabolic circuits on Earth came about.

Some scientists now argue that there is an "energy-based misreading of thermodynamics" at the center of bioenergetic discussions of life. This misreading stems from "the conceptual mistake to regard energy as the physical quantity whose consumption or use is what drives endergonic [or "up-hill"] processes."[22] Here, the investment is always with

> the 'use' of energy: by the particular metabolic processes that are said to 'conserve energy', by the energy that can be extracted from certain so-called 'high energy' chemical bonds (most famously and centrally the terminal phosphoanhydride bond in ATP…), by the energy 'consumed' to make certain up-hill reactions go, or to power physical movement, trans-membrane pumping, structural assembly and disassembly, and the like.[23]

"Common understanding" and conventional biochemistry are both invested in tracking energy. If the latter is criticized on these grounds, the expected defense is that the discussion is in reality about *free* energy rather than energy in general. Free energy legitimates this because it takes into account the "second law tax" by indicating that energy transfer is never without loss, therefore making it a more 'realistic' representation of the energy available to do work.

In this energy-transfer schema, entropy operates in two ways. First, it becomes "a tax that must be paid when using energy" that converts energy into free energy that is available to do 'work.'[24] Second, entropy can also be understood as a strange peculiarity of matter that causes things to run down and decay. Here, "[e]ntropy, in the conventional view, is certainly not what keeps life running, nor what it is struggling for. Much less can the ways of entropy be in any way given credit for the existence of organized states of matter and dynamically persistent

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[22] Elbert Branscomb, Tommaso Biancalani, Nigel N. Goldenfeld, and Michael J. Russell, "Escapement mechanisms and the conversion of disequilibria; the engines of creation," *Physics Reports* 677 (2017): 39.
[23] Branscomb et al., "Escapement mechanisms," 39
[24] Branscomb et al., "Escapement mechanisms," 38.

processes."[25] That the processes that mark life, including metabolism, are fundamentally about the *dissipation* of *disequilibria* rather than the consumption of energy is made clear if one remembers that ''free energy"—contrary to its general scientific usage—is actually a term that actually concerns entropy.[26] P.W. Atkins directly addresses this point in *The Second Law*:

> Reactions fall to lower free energy just as initially stationary particles fall to lower potential energy. Here lies a deep analogy between dynamics and thermodynamics. However, there is a crucial difference that must be borne in mind. We have constantly stressed that thermodynamic systems do not tend toward states of lower energy. Therefore the tendency to fall to lower free energy must not be interpreted literally in terms of falling down in energy. *The Universe falls upward in entropy*: that is the only law of spontaneous change. The free energy is, in fact, just a disguised form of the total entropy of the Universe, even though we have introduced it in a way that might conceal the connection, and even though it carries the name 'energy.'[27]

That free energy is a disguised form of total entropy in the Universe begins to connect to how a proto-metabolism would unfold from, and continue to dissipate, disequilibria:

> the root error…is in part that ''free energies'' are not physically measuring an energy—history, units, and convention notwithstanding. Physically, they are measuring an entropy difference—equivalently a ''probability'' difference. And that therefore disequilibria conversion must be understood, and analyzed in terms of, *the reduction of the entropy of one system* as *driven by* the (greater) *increase in the entropy of another*.[28]

Furthermore, it should be emphasized that it does not matter how much energy is input into a system—no amount of energy input can generate life as this frame of reference leads to a deceptive understanding of metabolism and its relation to disequilibrium:

> We emphasize that from this perspective, life's essential launching requirements were not ''building blocks'', i.e. not particular molecules, or classes of them, at any concentration

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[25] Branscomb et al., "Escapement mechanisms," 39.
[26] Though I will not directly address this here, the mathematical relation between entropy and free energy as expressed by the Gibbs free energy can be found here: http://2ndlaw.oxy.edu/gibbs.html.
[27] P.W. Atkins, *The Second Law: Energy, Chaos, and Form* (Scientific American Library: New York, 1994), 171, emphasis added.
[28] Branscomb et al., "Escapement Mechanisms," 39, emphasis added.

> or in any mix. Such a ‘‘soup’’ however produced, cycled, or concentrated; no matter what its constitution, and regardless of what chemically non-specific ‘‘energy’’ inputs were supplied to it, stably or otherwise—is in no meaningful way ‘lifelike’, nor capable, we assert, of engendering it. It would be as exactly useless to emergent life, and in part for the same fundamental chemical and thermodynamic reasons, as is ATP for extant life when not dynamically maintained in a high state of disequilibrium.[29]

Origins research that operates under the assumption that a simply large input of energy is needed for life to emerge utilizes the idea that life is simply "chemistry in a bag."[30] Chemistry in a bag works in tandem with the idea of life beginning as a soup. This is a problem because "soup is homogeneous in pH and redox potential, and so has no capacity for energy coupling by chemiosmosis."[31] The law of mass action applies to equilibrium chemistry. It decrees that that concentration of reactants and products in a closed system will move forward until there is equal concentration between reactants and products. The vacillation between reactants and products will shift at the microscopic level but will remain at constant at the macroscopic level.

Chemistry in a bag—that is to say, a number of biological precursors in close proximity—cannot generate a proto-metabolism regardless of how much *external energy* is input into the system. Metabolism, at its most fundamental level, *is about the flow of entropy or disequilibrium rather than energy*. Instead of external packets of energy being fed into a system, metabolism only arises through what is known as thermodynamic *coupling*. This coupling requires what some scientists term "engines." An engine here is any system that converts disequilibria (more specifically, an engine here is one that dissipates one disequilibrium by generating another). On this Russell, Nitschke, and Branscomb write:

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[29] Branscomb et al., "Escapement Mechanisms," 42.
[30] Elbert Branscomb and Michael J. Russell, "Frankenstein or a Submarine Alkaline Vent: Who is Responsible for Abiogenesis? Part 2: As life is now, it must have been in the beginning," *Bioessays* 40 (2018): 1700182.
[31] Lane, Allen, and Martin, "How did LUCA make a living?," 271.

> …the second law requires that life is essentially a construct of FEC [free-energy conversion] engines—all the way up as well as all the way down. These considerations support the proposition that FEC engines were the essential enabling inventions at life's very onset, although this is admittedly not the general view of the matter. The question, of course, comes down to whether life can begin exclusively with chemistry operating at (or very near) equilibrium. If the answer is no, then some reactions must be driving significantly away from equilibrium, driven, that is, in spite of being endergonic, and this, by the second law, inescapably requires that they be coupled to a thermodynamically larger exergonic reaction via an FEC engine.[32]

Thermodynamic coupling refers to how an up-hill (or endergonic) 'improbable' process is always coupled to a larger probable' reaction that is "disequilibrium-dissipating." The driving reaction moves in the opposite direction as the driven reaction:

> [l]iving systems inherently depend on a host of endergonic, thermodynamically 'up-hill', reactions each of which must therefore be forced, or driven, by being coupled to a thermodynamically larger down-hill (exergonic) reaction. Such coupling processes effect a conversion of thermodynamic disequilibria, creating one by dissipating another. They require the mediation of a particular type of "mechano-molecular" device: which does not act merely as an enzyme, whose action inherently ''transcends'' chemistry*, and which does not function by the transfer or ''consumption'' of energy.[33]

An origins theory that could address the beginnings of metabolism would be rooted in nonequilibrium thermodynamics. In this framework, a powerful physical or chemical process striving to dissipate itself would be used by an *engine* to generate another disequilibrium *that an infantile metabolism could make use of.* This engine thus would generate a form of disequilibrium that would be usable for life, and in doing so, further drive the dissipation of the original disequilibrium. Origins research that experiments with disequilibrium-converting *engines* at the core of metabolism is able to address the genesis of metabolism as well as its continuing complexification and evolution.

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[32] Michael J. Russell, Wolfgang Nitschke, and Elbert Branscomb, "The inevitable journey to being," *Philosophical Transactions of the Royal Society B* 368 (2013): 20120254.
[33] Russell et al., "Escapement Mechanisms," 1, emphasis added.

3.4 The Machines of Maternal Engines, or, Metabolism as Machinic Biology

Some of the key origins researchers who argue that metabolism came prior to the emergence of genetics theorize the emergence of metabolism in the far-from-equilibrium inorganic wombs (or "semipermeable compartmentation") found at certain (namely, alkaline) deep-sea vents.[34] While the idea of a metabolism-first foundation for the emergence of cellular life works in tandem with womb-like thinking, what constitutes this proto-metabolism is still actively being debated and tested. Rather than present every possible scenario that has been put forward, in this section, I focus on how particular understandings of the nature of metabolism may bring us closer to a metabolism suited for feminist philosophy of life. I also explore how such a metabolism would reinvent the concepts of "machine" and "engine," and therefore help us conceptualize the metabolic workhorses of life: proteins. The inorganic ingredients needed to form these workhorses exist in the geochemical spaces of hydrothermal vents and contemporary research does a great job of cataloguing the chemical "building blocks" of metabolism. What is missing from such accounts is how and why a proto-metabolism would come about.

If life, in a basic and primordial sense, consists of engines that convert disequilibria (rather than consume energy), my aim is to rethink the concept of "machine" when it is embedded in a logic of at least two. How might a logic rooted in sexual difference (of at least two-ness) be able to account for an organic theory of machines?

Biological textbooks often discuss the inner workings of a cell, particularly proteins, as molecular machines. They do this without being able to account for (or even address) the origins of such machines, which in modern day organisms are so specific and tailored to their function

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[34] This was my focus in my previous chapter on "primordial wombs."

that a recourse to creationism often occurs. As a theoretical alternative to this, I will focus on research that speculates on the origins of enzymes. Most biological enzymes are proteins, except for certain kinds of RNA (which will be the focus of the next chapter). From a microscopic prospective, proteins are molecular machines: they have machinic parts such as rotary engines (rotar, stator, and driveshaft) and pumps. If metabolism requires machines to come into being, in what follows, I will consider what kind of theory of machine can be generated by maternal engines of disequilibria. On this point, three researchers write:

> Life is evolutionarily the most complex of the emergent symmetry-breaking, macroscopically organized dynamic structures in the Universe. Members of this cascading series of disequilibria-converting systems, or engines…become ever more complicated—more chemical and less physical—as each engine extracts, exploits and generates ever lower grades of energy and resources in the service of entropy generation. Each one of these engines emerges spontaneously from order created by a particular mother engine or engines, as the disequilibrated potential daughter is driven beyond a critical point…[35]

Here, the idea of self-organization is directly tied to a concept of a mother or "maternal" engine. This maternal engine is a particular process that affirms the second law of thermodynamics by increasing the entropy of the universe. In doing so, this maternal engine provides the conditions for daughter engines to arise that are *coupled* to the dissipation of such processes. It is the larger dissipative desire of the maternal engine that drives the self-organization of a daughter engine—in short, the daughter engine hinges on a maternal engine's drive to dissipate. An "offspring" engine that constitutes itself is not possible—the movement of life consists of engines that convert (and thereby make usable) one form of disequilibria to another. If proto-metabolism requires nano-engines—in other words, if it requires disequilibria converters to mediate between (down-hill) driving and (up-hill) driven reactions—this entails a reassessment of the concept of

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[35] Russell, Nitschke, and Branscomb, "The inevitable journey to being," 20120254.

"machine" in relation to metabolism and biology more broadly. What new relationship between "machine" and metabolism can be developed through the logic and language of maternal engines?

To begin to answer this question, we can address how "machine" has been understood in the history of thought. One intriguing place to start is with Hans Jonas's philosophical project. In *The Phenomenon of Life,* Jonas seeks "an 'existential' interpretation of biology facts."[36] His goal is to use existentialism and scientific biology together in order to undo each field's respective limits: existentialism is confined by its anthropocentrism while biology is hampered by its materialism.[37] Because it is far too solely concerned with "man," existentialism ascribes what may "be rooted in organic existence" only to him. Scientific biology, on the other hand, "by its rules confined to the physical, outward facts, must ignore the dimension of inwardness that belongs to life: in so doing, it submerges the distinction of 'animate' and 'inanimate'" in the direction that all of biology becomes *in*animate.[38] To counter these two limitations, Jonas's goal is to develop "a psychophysical unity of life" where the inner dimension of life is not discarded so as not to repeat "the divorce of the material and mental since Descartes."[39]

When comparing an organism to a physical or "ordinary" inorganic body, what is most striking for Jonas are the "special goings-on" that occur "both inside and outside its so-called boundary, which will render its phenomenal unity still more problematical than that of ordinary bodies, and will efface almost entirely its material identity through time….[In other words, an

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[36] Hans Jonas, *The Phenomenon of Life: Toward a Philosophical Biology* (Evanston, Illinois: Northwestern University Press, 1966), ix.
[37] More than this, existentialism has itself disavowed biology as irrelevant to consciousness for being-for-itself. In linking it to the body, as Merleau-Ponty also does, Jonas is expanding and transforming both existentialism and phenomenology.
[38] Jonas, *The Phenomenon of Life*, ix.
[39] Jonas, *The Phenomenon of Life*, ix.

organism's] *metabolism*, its exchange of matter with the surroundings."[40] In this view, the material components of an organism are exceedingly temporary. Due to this, a solely materialistic explanation of metabolism cannot suffice. Such material components are

> passing contents whose joint material identity does not coincide with the identity of the whole which they enter and leave, and which sustains its own identity by the very act of foreign matter passing through its spatial system, the living *form*. It is never the same materially and yet persists as its same self, *by* not remaining the same matter.[41]

The concept of living form suggests that the metabolic machines have a certain incorporeal quality that cannot simply be understood by their material parts. Jonas recognizes that sameness implies equilibrium—and therefore death: "if any two 'time slices' of it become, as to individual contents, identical with each other and with the slices between them—it ceases to live [or, in the case of spores, stops to exist until the appropriate conditions arise]."[42]

For Jonas, it is the "subject of life" itself that marks the first expression of freedom in his search for an existential biology. He compares metabolism to a material exchange between inside and out by likening it to an engine as it is generally understood in the context of human-made machines. On this, he writes:

> The metaphor of 'inflow and outflow' does *not* render the radical nature of the fact. In an engine we have inflow of fuel and outflow of waste products, but the machine parts themselves that give passage to this flow do not participate in it: their substance is not involved in the transformations which the fuel undergoes in its passage through them; their physical identity is clearly a matter apart, affected neither by those interchanges nor by their ensuring action. Thus the machine persists as a self-identical inert system over against the changing identity of the matter with which it is 'fed'; and, we may add, it exists as just the same when there is no feeding at all: it is then the same machine at a standstill.[43]

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[40] Jonas, *The Phenomenon of Life,* 75.
[41] Jonas, *The Phenomenon of Life,* 76, emphasis in original.
[42] Jonas, *The Phenomenon of Life,* 76.
[43] Jonas, *The Phenomenon of Life,* 76, emphasis added.

A human-centric idea of an inert machine in the context of a proto-metabolism tied to disequilibria will not hold. If metabolism must address living form, this form must embody the machinic qualities of metabolism itself. What Jonas is outlining here is a Cartesian theory of machine—something that is without soul and inanimate and in distinguishable from "what it is fed." Such a machine is one that is organized from a human understanding of how to make a machine: a machine makes something separate from itself using components that are 'fed' into it (following an input/output logic). Such a conception of machine, which Jonas is critiquing, echoes Hird's rendering of metabolism.

Jonas contrasts this notion of machine to a metabolizing system as a whole. On this, he writes:

> On the other hand, when we call a living body 'a metabolizing system,' we must include in the term that the system itself is wholly continuously a result of its metabolizing activity, and further that none of the 'result' ceases to be an object of metabolism while it is also an agent of it. For this reason alone, it is inappropriate to liken the organism to a machine. The first to do so was Descartes, and his model (designed from the outset for animals and not for plants) already provided, besides the *structure* of moveable parts, for a source of *power* to make them move: the heat generated by the 'burning' of the food. Thus the combustion theory of metabolism complements the machine theory of anatomical structure. But metabolism is more than a method of power generation, or food is more than fuel: in addition, and more basic than, providing kinetic energy for the running of the machine (a case anyway not applying to plants), its role is to build up originally and replace continually the very parts of the machine. Metabolism thus is the constant becoming of the machine itself—and this becoming itself is a performance of the machine: but for such performance there is no analogue in the world of machines.[44]

Jonas here comes very close to articulating a metabolic concept of a molecular machine. This machine would not, or more specifically, could not, be separate from the inflow and outflow of fuel and waste. The machine parts would have to participate in, and be affected by, this exchange—in short, their existence would be entirely dependent on the system and they therefore

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[44] Jonas, *The Phenomenon of Life,* 76.

would cease to exist if the system they were embedded within eroded. If metabolism, in touch with living form, always exceeds a system's temporary material components, its machinic parts cannot idly rest. Though there is no analogue of this "constant becoming of the machine itself" at the level of human-machines, I argue that Jonas gestures towards the kind of biological machinery that emerged for proto-metabolism to begin through the concept of living form.

As some have actual pumps and rotors, proteins are complicated machines that perform the vast majority of vital processes within a cell. They are machines that are exceedingly complex, and are capable of such complicated biological functioning that they cause unease from a materialist scientific perspective that wishes to understand the evolution of such machines in a gradual step-by-step manner. Take, for example, the ATP Synthase. This enzyme is a dual rotor pump embedded within the plasma membrane of ("simple") prokaryotic cells.[45] ATP Synthase generates ATP—or adenosine triphosphate, the "energy currency" of cellular life—by harnessing the disequilibria of proton (H^+) gradients externally surrounding their membranes. The complexity of the ATP Synthase tangibly makes origins of life researchers nervous.[46] It becomes difficult to theorize the evolution of such a machine in a gradual manner. The ATP Synthases found in archaea and bacteria "famously stand at the apex of complexity and sophistication of design as engines of free energy conversion."[47] In other words, it becomes difficult to postulate how such machinery could be made through a series of causal (or even just ordered temporal) steps.

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[45] ATP Synthase also lines the inner membrane of mitochondria, the organelle in complex eukaryotic life that is the powerhouse of the cell because it produces the bulk of cellular ATP.
[46] Russell, Nitschke, and Branscomb, "The inevitable journey to being," 20120254.
[47] Russell, Nitschke, and Branscomb, "The inevitable journey to being," 20120254.

If the engines that mark the emergence of life cannot be equated with a Cartesian animal machine, perhaps an alternative theory of "machine" can bring us closer to theorizing what Jonas refers to as "the becoming of the machine itself." In *Creative Evolution*, Henri Bergson's outlines the ways in which the concept of "machine" operates in mechanistic and finalistic approaches to evolution. In a way, Bergson anticipates the theoretical lacuna in origins research regarding proto-enzymes. Such research falls under what he terms a "mechanistic theory." He writes:

> A mechanistic theory is one which means to show us the gradual building-up of the machine under the influence of external circumstances intervening either directly by action on the tissues or indirectly by the selection of better-adapted ones. But, whatever form this theory may take, supposing it avails at all to explain the detail of the parts, it throws no light on their correlation.[48]

The chemical compounds that function as powerful analogues to extant enzymes, especially their metallic cores, abound in alkaline vents. Trace elements that are vital for life, even ones that are exceedingly rare on Earth, are thought to have been present and available in these deep ocean spaces. This suggests that the spatiotemporal location of the chemical components of life have been pinpointed. If material components exist, how are enzymes—the beginnings of biological machines—generated?

In contrast to mechanism, the doctrine of finality would argue "that the parts have been brought together on a preconceived plan with a view to a certain end."[49] In this respect, finalism "likens the labor of nature to that of a workman" and thus has an anthropomorphic character. Bergson argues that mechanism is also tainted with the same anthropomorphic problem. Like finalism, mechanism "also holds that nature has worked like a human being by bringing parts together, while a mere glance at the development of an embryo shows that life goes to work in a

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[48] Bergson, *Creative Evolution*, 98.
[49] Bergson, *Creative Evolution*, 98.

very different way. Life does not proceed by the association and addition of elements, but by dissociation and division."[50] Both finalism and mechanism are modeled by the human intellect, which creates concepts that provide it with the practical ability to act on them. In this sense mechanism and finalism are dually anthropomorphic: "We must get beyond both points of view, both mechanism and finalism being, at bottom, only standpoints to which the human mind has been led by considering the work of man."[51] Simply put, "[b]oth doctrines are reluctant to see in the course of things generally, or even simply in the development of life, an unforeseeable creation of form."[52] To counter this, Bergson suggests that the becoming of a biological machine should be theorized, like the formation of the eye, by attending to the "complexity of its structure and simplicity of its function."[53] Can an eye be constructed simply through the bringing together of external parts? Or does it require an altogether different conceptualization of organic becoming?

Bergson's distinction between *manufacturing* and *organization* is useful for contemplating machine-becoming. He identifies manufacturing as an operation specific to man-made machines. This is because it assembles matter that has been *precut* in order to later fit them together "for a common action."[54] This entails working from "periphery to center." In contrast, organization works "from the center to periphery."[55] He carefully distinguishes between these two modes of machinic construction. In the case of organization,

> [i]t begins in a point that is almost a mathematical point, and spreads around this point by concentric waves which go on enlarging. The work of manufacturing is the more effective, the greater the *quantity* of matter dealt with. It proceeds by concentration and

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[50] Bergson, *Creative Evolution*, 98
[51] Bergson, *Creative Evolution*, 99.
[52] Bergson, *Creative Evolution*, 80-1.
[53] Bergson, *Creative Evolution*, 98.
[54] Bergson, *Creative Evolution*, 103.
[55] Bergson, *Creative Evolution*, 103.

> compression. The organizing act, on the contrary, has something explosive about it: it needs at the beginning the smallest possible place, a minimum of matter, as if the organizing forces only entered space reluctantly.[56]

In contrast, manufacturing creates best in bulk. Perhaps most telling, Bergson argues that "a manufactured thing delineates exactly the form of the work of manufacturing it."[57] The labor involved in manufacturing seamlessly correlates with the product itself. This holds true for the machine as a whole as well as for each particular component. Organization, in contrast, offers no correlation between the organizing work and the organized thing. There are no aggregate parts that come externally together in the case of organization.

Positive science, according to Bergson, will treat organization as though it is like a machine:

> Now I recognize that positive science can and should proceed as if organization was like making a machine. Only so will it have any hold on organized bodies. For its object is not to show us the essence of things, but to furnish us with the best means of acting on them.
>
> Physics and chemistry are well advanced sciences, and living matter lends itself to our action only so far as we can treat it by the processes of our physics and chemistry. Organization can therefore only be studied scientifically if the organized body has first been likened to a machine. The cells will be the pieces of the machine, the organism their assemblage, and the elementary labors which have organized the parts will be regarded as the real elements of the labor which has organized the whole. This is the standpoint of science. Quite different, in our opinion, is that of philosophy.[58]

In contrast to a manufactured machine, the parts of an organized machine would not resemble the method that generated them. He argues that this is "because the materiality of this [organized] machine does not represent a sum of means employed, but a sum of obstacles avoided: it is a

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[56] Bergson, *Creative Evolution*, 103.
[57] Bergson, *Creative Evolution*, 103.
[58] Bergson, *Creative Evolution*, 103-4.

negation rather than a positive reality."[59] The organizing forces of said machine "reluctantly" enter into space and provide the possibility of action.[60] The genesis of machines that mediate driving and driven reactions initially enter into space in a small yet "explosive" way. The genesis of an organized machine in a Bergsonian sense would reorient the very idea of a machine itself.

Jonas shares with Bergson the view that vital organization, a biological body, can never be equated to a machine that is human-made. For Jonas however, metabolism signals that there is the possibility of the becoming of the machine itself. Perhaps a machinic concept that is in touch with living form (while the material components are constantly exchanged) can generate an idea of organization that could address machinic becoming itself. One could argue this remaking of the idea of "machine" is only gaining in momentum as molecular biology and nonequilibrium thermodynamics advance (not to mention its reactivation in Deleuze, and Deleuze and Guattari). What such research cannot (or chooses to not) address is how organizing forces create a machine from the center to the periphery in a way that is an unfolding of a unity rather than preexisting parts arranged to fit together to form a composite whole.[61]

If we consider enzymes as machines, their architecture is not only complex, but also highly dynamic. These proteins often have different configuration states that involve a shift in spatial rearrangements from their non-activated form to their activated forms (i.e., their spatial configuration when they bind a target substrate). Indeed, the conformational precision of enzymes places pressure on how different biochemistry is from chemistry and whether understanding enzymes as *catalysts* that are simply biological captures their complexity:

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[59] Bergson, *Creative Evolution*, 103-4.
[60] Bergson, *Creative Evolution*, 103.
[61] Bergson locates the instinct as the faculty that constructs and uses organized instruments while intelligence is adept at making and using unorganized instruments (Bergson, *Creative Evolution*, 155.)

> Implicit in such cyclic reaction schemes …is the fact that the protein complex mediating a conversion passes through a corresponding ordered series of alternate enzyme forms in each of which it takes on distinct binding and catalytic properties. In operation, the completion of the task of each of these alternative enzyme forms triggers the transition to the next one in the cycle…However, this operational characteristic makes explicit that these devices are not just catalysts, i.e. entities that passively accelerate a reaction that would take place on its own. Nor even are they just 'enzymes' in the ordinary sense denoting biological catalysts. They are true engines, in spirit and operation;…they do and must 'transcend chemistry.'[62]

Such machines would need to be produced from the inside out; organized rather than manufactured. The language of engines and machines *sui generis* seem necessary. A becoming of machines, required for proto-metabolism and disequilibria between (at least) two processes, is needed for the emergence of life. Even though Bergson's argument is historical, it remains a powerfully astute diagnosis of what mechanistic biology is incapable of addressing: the *complexity* of machinic structure and *simplicity* of machinic function. Within contemporary origins research, using the framework of disequilibria driver and driven reactions — in other words, within the thermodynamic logic of at least two—an organized becoming of an engine begins to unfold.

[62] Branscomb et al., "Escapement mechanisms," 11.

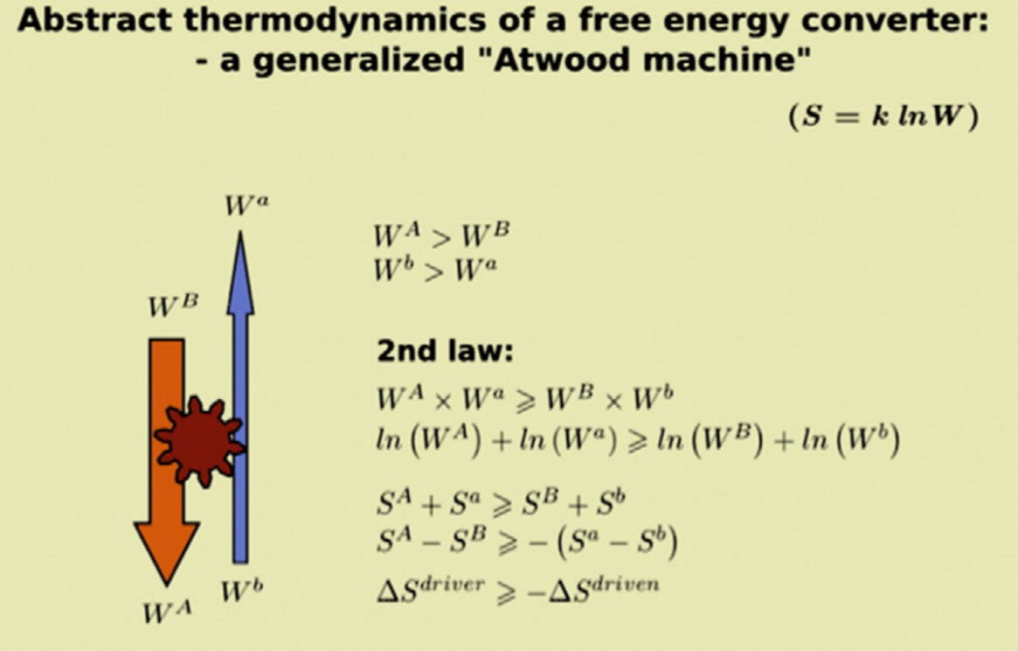

Figure 9: Abstract thermodynamics of a free energy converter - a generalized 'Atwood machine' (Branscomb and Russell, 2013)

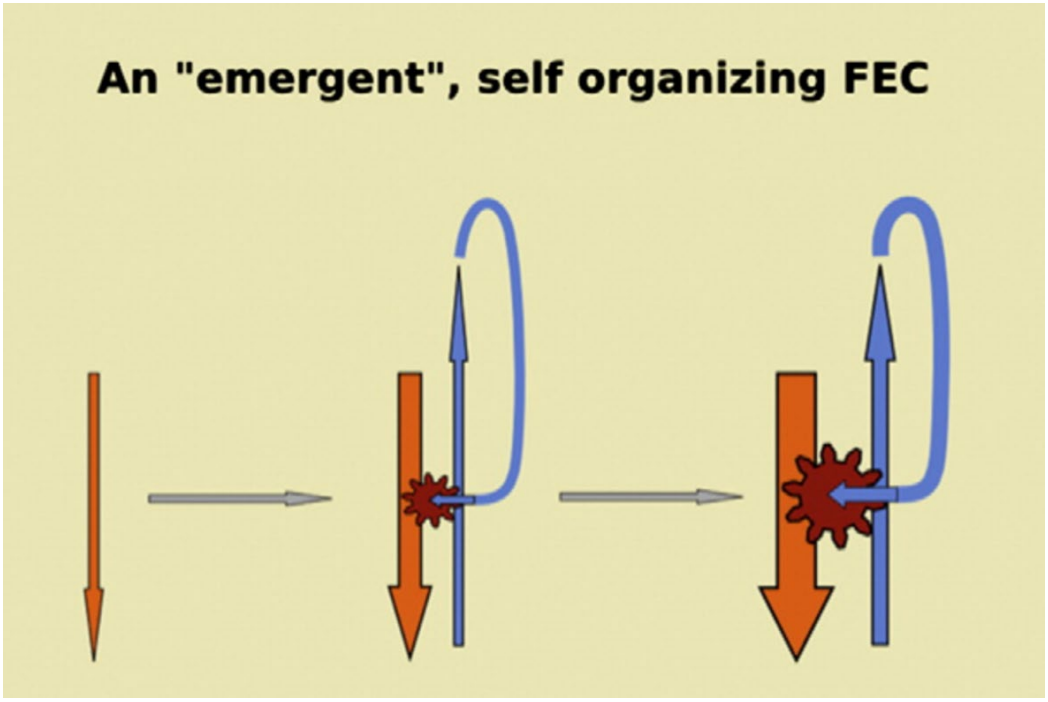

Figure 10: "An Emergent, self-organizing FES" (Branscomb and Russell, 2013)

Figures 9 and 10 suggest how an "Atwood machine" would spontaneously emerge in far-from-equilibrium conditions. Named after English mathematician George Atwood, an Atwood machine is used in general physics to demonstrate acceleration and dynamics. A frictionless pulley connects two objects of two masses. The object with the larger mass, when moving down, pushes the object with lighter mass up. An Atwood machine, generally, has no relation to self-organizing processes. In both figures above, however, a theory of a self-organizing Atwood machine as free-energy (or disequilibria) conversion engine is suggested. Branscomb and Russell discuss how in "very far-from-equilibrium disequilibria," an "uphill" endergonic reaction can be driven by being coupled to a larger dissipating driving reaction, and in doing so, result in the "self"-organization of an engine. The birth of machinic form exists at the interstices of these two processes in tension.

The engine that is formed is thermodynamically tied to and dependent on the disequilibria. In both figure nine and ten, the blue arrow represents an uphill "anti-entropic" process that can *only* occur by being coupled with the larger disequilibrating process (represented by the red arrows in the figures above). Once coupled, which is shown in figures 9 and 10, an engine emerges when the process becomes autocatalytic, in other words, when the anti-entropic processes *accelerate* the dissipation of the initial disequilibrium (displayed here by how the red arrows increase in size in figure three). The dissipating disequilibrium is always greater in magnitude than the uphill order-generating "anti-entropic" process (which is why the red arrows in figures above are always larger in size than their coupled blue arrows). An engine rests at the center of this autocatalytic tension.

If the origins of metabolism entailed a self-organizing process, employing an idea of energy that can move, rearrange, or bring together external parts is futile. This is because *there were no pre-existing parts to organize*. Self-organization does not operate through inputs of external energy. Instead, order is generated through small fluctuations that become available to the system when it is at far-from-equilibrium. Rather than an external input of energy, this process *requires entropy* and *disequilibrium.* Indeed, the language of "self" organization here seems itself to not adequately express the actual movements of this genesis. The "self" that is organized is not self-making; instead this self-making is attributed to the larger driving disequilibria. The maternal engine generates an autocatalytic cycle where a "self" is birthed in order to further strengthen its own dissipation:

> In many naturally arising FEC [free-energy conversion] engines, i.e. the so-called "emergent" or "self organizing dissipative structures" ("SODS"), the driving gradient creates its *own* coupling "gear" from nothing: the macroscopically organized state of matter that mediates the turnstile coupling between the driving and driven process is produced—forced into existence—*by the driving [maternal] gradient itself.* In these cases the FEC-mediating organized structure is itself part of the "disequilibrium" that the FEC is creating through its driven flux. It is due to this positive, 'autophagic', feedback

> behavior that the engine is "autocatalytic" and thereby self-generating or emergent. The engine quite literally consumes (or 'feeds on') its own work output to achieve stability and growth…hydrothermal convection cells are beautifully illustrative examples. Importantly, such entirely self-generating FEC systems come into existence only in response to very far-from-equilibrium disequilibria (as Prigogine and his collaborators were the first to study in detail).[63]

The language of "self" here, because it is so intimately bound up with disequilibrium, begins to gain a different consistency than an autonomous self that makes itself. Autocatalysis is a term that points to how a system feeds and maintain itself and thereby becomes a network. Coined by Manfred Eigen (who won the Nobel Prize in Chemistry in 1967), autocatalysis addresses how reactants being fed into a reaction eventually generate a network where the reaction products become reactants. To the concept of autocatalysis, the authors offer the metaphor of autophagy. The larger "maternal" engine itself generates the conditions to accelerate its own dissipation. The increase of the dissipation of the larger, driving reaction "is conditional on, in fact gated by, the progress of the ["uphill"] driven process."[64] The coupling between "mother" and "daughter" reactions exist in a kind of productive tension where one cannot be disentangled from the other and where one depends on the movement of the other. The driving "maternal" gradient creates a driven reaction that temporarily exhibits order. The generation of order by the driven reaction accelerates the dissipation of the "maternal" gradient itself. The logic suggested here is one of intimate imbrication.

If this model suggests a possible origin for bioenergetics, the researchers argue that its elaboration necessitates "searching for the founding mothers of biological FEC [free-energy conversion] in the 'lost cities' of the [ancient] Hadean sea."[65] In relation to this, the researchers

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[63] Branscomb and Russell, "Turnstiles and Bifurcators," 65, emphasis added.
[64] Branscomb et al., "Escapement mechanisms," 5.
[65] Branscomb and Russell, "Turnstiles and Bifurcators," 67.

speculate on *proteins* that use metal at their active centers as the first possible free-energy conversion engines. The protein of choice used to speculate the birth of molecular machines is an iron-containing protein called Ferredoxin 1 protein. This protein as a proto-engine is considered first and foremost because of its geochemical availability in relation to alkaline vent theory: the core components of ferredoxins, iron-sulfur cuboidal structures, are congruent with the iron-sulfur compounds found at deep-sea vents. The second reason why ferredoxins are one of the first engines is more intriguing and involves the capabilities of metals to perform crucial chemical reactions that non-metals cannot. A machinic theory of birth here capitalizes on the properties of metals that make them well-suited to possibly being the first proto-biological disequilibria engines.

3.5 Meditating Disequilibria, or, What Metals Bring to Life

Most elements on the Periodic Table are metals.[66] Metals have a tendency to donate or lose valence electrons easily and become positive ions, or cations.

[66] A group of elements that border transition metals and the non-metal elements on the far right of the table are classified as "metalloids." In the table below, metalloids are elements with a dotted border around them, Boron (B), Silicon (Si), Germanium (Ge), Arsenic (As), Antinomy (SB), and Tellurium (TB) are metalloids. Metalloids exhibit properties of both metals and nonmetals.

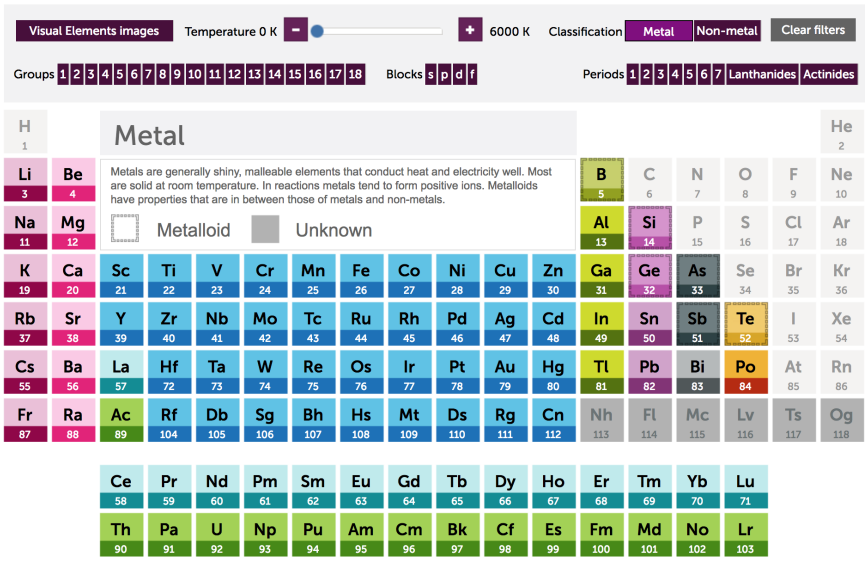

Figure 11: A Representation of the Periodic Table where the Colored Elements are Metals (Royal Chemical Society)

The metals in the middle of the Periodic Table are known as transition metals. Most transition metals are particularly adept at being multivalent. In other words, they can readily exist at different "oxidation states." An oxidation state is a number that indicates whether an ion has gained or lost electrons compared to its "neutral" atomic form. [67] For example, Iron (Fe) can lose two electrons and exist as Fe^{2+}, which signifies that it now has two less electrons than protons. Fe^{2+} can further willingly lose another electron to form Fe^{3+}. This unique ability to easily gain and donate electrons makes transition metals such Iron particularly useful reagents in oxidation-reduction reactions (or redox reactions). Redox reactions are a type of chemical reactions in which there is a flow of electrons from one agent to another; one reagent is 'oxidized' or *loses* electrons while a different reagent is "reduced" or *gains* electrons. This metallic ability to swiftly

[67] Oxidation is a chemical reaction in which there is a loss of electrons by one atom and a gain by another. The atom which loses an electron has an *increase* in its oxidation state, while the atom that gains the electron has a *decrease* in its oxidation state.

gain and donate electrons directly relates to origins research that speculates on ferredoxins being the first free-energy or disequilibria converting engines that formed an initial proto-metabolism. I will return to this point below after a consideration of how these capacities of metals reorient the relation between what is nonliving and living.

In his well-known essay "Nonorganic Life," Manuel DeLanda suggests that since the mid-twentieth century, there has been a paradigm shift in scientific research concerning the central role of "conservative systems" in thermodynamics. These are physical systems that "for all practical purposes, are isolated from their surroundings."[68] The focus on and privileging of closed systems "is giving way to the realization that *most systems in nature* are subject to flows of matter and energy that continuously move through them."[69] This paradigm shift has resulted in a whole host of nonequilibrium processes to be found across Nature, and open systems, understood as anomalies to be explained away in a previous paradigm that privileged closed-state equilibrium, are now increasingly becoming the center of scientific research.

Self-organizing reactions only occur in situations where there is a constant flow of matter/energy into the system. If matter ceases to be "blind" in far-from-equilibrium conditions, the potential for organic biological machines to arise in such conditions becomes possible. [70] In such conditions, "[m]atter, it turns out can 'express' itself in complex and creative ways, and our awareness of this must be incorporated into any materialist philosophy."[71] If matter can "see," if it comes "alive" in these conditions, it is because, as Deleuze and Guattari assert, it is in direct relation to the machinic phylum. DeLanda understands the machinic phylum to be

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[68] Manuel DeLanda, "Nonorganic Life," in *Incorporations*, ed. Jonathan Crary and Sanford Kwinter (New York: Zone Books, 1992), 129.
[69] DeLanda, "Nonorganic Life," 129, emphasis added.
[70] DeLanda, "Nonorganic Life," 13.
[71] DeLanda, "Nonorganic Life," 133.

> the abstract reservoir of machinelike solutions, common to physical systems as diverse as clouds, flames, rivers and even the phylogenetic lineages of living creatures,…a term that would indicate how nonlinear flows of matter and energy spontaneously generate machinelike assemblages when internal or external pressures reach a critical level, which only a very few abstract mechanisms can account for. In short, there is a single machinic phylum for all the different living and nonliving phylogenetic lineages.[1]

To this I would add that the machinic phylum is a domain of sense that subsists in both nonliving and living lineages. The machinic phylum is what would engender, to use Jonas' phrase, living form. DeLanda reminds us that "[a]mong all the elements, the most powerful catalysts are metals, and for this reason metals have been said to bear a privileged status in the machinic phylum."[2] Metals are where the presence of the machinic phylum is most directly felt because their dynamic chemical properties allow us to glimpse a "material vitalism" that exists everywhere but that is almost always covered over. They thus easily embody a Nature that is permeated by flows of matter and energy. Metals, like water, have a complex morphology, one that is constituted by *flow* and therefore able to endlessly form and deform in a way that makes their "sea" of electrons able to powerfully catalyze reactions.

DeLanda notes how metals have a privileged position in the "machinic phylum" due to their powerful catalytic abilities. On this, he cites Deleuze and Guattari from *A Thousand Plateaus*:

> In short, what metal and metallurgy bring to light is a life proper to matter, a vital state of matter as such, a material vitalism that doubtless exists everywhere but is ordinarily hidden or covered, rendered unrecognizable, dissociated by the hylomorphic model. Metallurgy is the consciousness or thought of the matter-flow, and metal the correlate of that consciousness. As expressed in pan-metallism, metal is coextensive to the whole of matter, and the whole of matter to metallurgy. Even the waters, the grasses and varieties of wood, the animals, are populated by salts or mineral elements. Not everything is metal, but metal is everywhere.[72]

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[72] DeLanda, *Deleuze: History and Science* (New York and Dresdon: Atropos Press, 2010), 78, citing Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. Brian Massumi (Minneapolis: University of Minnesota Press, 1987 [1980]), 406.

As I outlined earlier, metals are indeed capable of flowing in ways that nonmetals are not. DeLanda recognizes and celebrates the ability of metals to act as powerful catalysts, but goes on to then differentiate the catalytic abilities of metals (which are broad and unspecific) to the "far more specific" effects of enzymes.[73] He acknowledges the crucial role catalysts must have played in the origins of life, but then makes a sharp distinction between inorganic catalysts like metals and enzymes as "living catalysts." On this, He writes:

> This special capability of catalysts to intervene in the dynamics of other processes is the necessary precondition of life. Indeed, the catalysts involved in living processes, called "enzymes" are far more specific than metals in their dynamic effects, allowing for much more detailed control of chemical reactions. The instructions for building each enzyme are stored in DNA, and thus allows this particular enzyme "designs" to be not only inheritable, but also capable of being fine-tuned for specific functions through the action of natural selection. Because the translation of sequence of DNA into enzymes is itself an activity regulated by enzymes, we seem to have here a classic chicken-or-egg dilemma.[74]

DeLanda's intuition that the special capability of catalysts to intervene in the dynamics of other processes as a necessary precondition for life to emerge is absolutely correct. Though life is not simply the biochemical quickening of geochemical reactions, when understood from a cellular thermodynamic perspective, enzymes speed up and therefore enable the autocatalytic closure of metabolic cyclic chemical reactions. Extant (i.e., present-day) enzymes are indeed much more specific than metals in their catalyzing ability.[75]

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[73] DeLanda, "Nonorganic Life," 144.
[74] DeLanda, "Nonorganic Life," 144.
[75] Metals can speed up a whole host of reactions—this is why they are used as industrial catalysts. Their general non-specificity makes metals, from the vantage-point of the present, ill-suited to catalyze biological reactions. Enzymes are much more specific to metals because they, over the course of evolution, have become precisely tailored to the reactions they catalyze. This present-day specificity, *however*, still has signs of simpler, "metallic" beginnings. One such sign is that many key modern-day enzymes—especially those thought to be the most evolutionarily ancient—have metal ions at their "active" centers. I address this in the chapter shortly. The biological specificity of enzymes was honed and developed over time, and metals are key to

Furthermore, DeLanda acutely recognizes the chicken-or-egg dilemma we face when we attempt to comprehend the emergence of life from the vantage point of the present, or as does Hird, from stasis: if enzymes are central actors across organic life, and are manufactured by cellular processes that first have to 'translate' DNA, how are we to understand the role (and existence) of enzymes in the emergence of life? What *did* come first? Though the central concept of his paper—nonequilibrium thermodynamics—creates the possibility to theorize the beginnings of cellular life, DeLanda's separation of metals as inorganic catalysts from biological enzymes preemptively suspends a consideration of how *metals* could have been the *first* catalysts for a nascent form of life. Emphasizing how catalytic capabilities are indeed the precondition of life, my aim for the remainder of this chapter is to demonstrate how tracking the catalytic capacities of metals in nonorganic *as well as organic* life affirms "a single machinic phylum for all the different living and nonliving phylogenetic lineages."[76]

One can unhinge DeLanda's division of metal from organic life by thinking about the origins of biological machines known as enzymes. Such a move can be achieved by attending to contemporary origins research in proteomics, geochemistry, and biochemistry, which all suggest that the catalytic abilities of *metals* played a crucial precondition for enzymes to emerge *before*, and in concert with, the birth of genetic systems. Perhaps the machinic phylum of metals can solve the chicken-or-egg dilemma once and for all. The slight dichotomization in DeLanda's work between "biology" and "non-organic" becomes unstable if one turns to origins research that considers what role metals may have had in the origins of life. If there is one machinic phylum, and metals most directly make evident the material vitalism that marks all of matter, I conclude

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understanding the origins of biological catalysis itself. This is what DeLanda fails to recognize in his theorization of nonorganic life.

[76] DeLanda, "Nonorganic Life," 136.

this chapter by centering the role of metals in the beginnings of proto-metabolism. In the alkaline vent hypothesis of the origins of cellular life outlined in chapter one, the semipermeable "inorganic wombs" that gestated the chemical reactions that marked the beginning of life were iron-sulphide wombs. These wombs were generated by the mixing of "sulphide-rich hydrothermal fluid" entering the ocean at these sites with the "iron(II)-containing waters of the Hadean ocean floor."[77]

Origins research that takes seriously the role of metals at alkaline vents considers how the geochemical presence of iron and sulphur at these sites, in addition to becoming wombs, could have also acted as inorganic catalysts. This is an especially interesting avenue of research if one considers how the iron-sulphide clusters found at the center of many contemporary enzymes are thought to be among the most ancient proteins across all of the domains of life. In keeping with the theory of life proposed here, this sign of metal within our cellular selves should be of no surprise. The machinic phylum, as a virtual reservoir that makes actualization possible, is in this sense metallurgical. In addition to how they see the energetics of metal as vital to life, in the theory of machines proposed here, one can further embed DeLanda, Deleuze, and Guattari in a maternal milieu that calls attention to the disequilibrium conditions under and through which metals become machinic in the origins of biological function.

A study as early as 1966 demonstrated the relationship between metals and proteins in a striking way.[78] When ferredoxins (a particular class of iron containing proteins) are denatured or unfolded, they can be "reconstituted" to "native ferredoxins" with the addition of iron and sulfur in a specific form. This denaturing and renaturing of a protein by removing and reintroducing

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[77] Martin and Russell, "On the origins of cells," 59.
[78] Richard Malkin and Jesse C. Rabinowitz, "The reconstitution of clostridial ferredoxin," *Biochemical and Biophysical Research Communications* 1966 23, no. 6: 822-827.

metal suggests that the bioorganic folds of life respond to metal in crucial ways. More recent research suggests that a particular kind of ferredoxin, FD1, is

> a representative biological FEC [free-energy converting or disequilibrium converting] device which mediates proton translocation anti-entropically (as the disequilibrium-creating driven reaction) using a redox reaction as the driving disequilibrium; in this system, that is, an electron flow and a proton flow are reciprocally coupled.[79]

Here, a metalloprotein folds into being through the flow of electrons. This is considered a "simple FEC mechanism" because the way it converts disequilibria is relatively simply: it couples "the passage of one proton to the passage of one electron."[80] Existing at the border of inorganic chemistry and biochemistry, here again, the *complexity* of machinic structure involves a *simplicity* of machinic function. Two scientists, Wim Hordijk and Mike Stee, further elaborate on the idea of a metallic origin of metabolism. They write:

> In modern-day life the chemical reactions making up an organism's metabolism are catalyzed by highly evolved enzymes (= protein + cofactor). However, there is increasing evidence that many biological reactions can be catalyzed by *inorganic elements alone*. Furthermore, many modern-day enzymes still use these inorganic elements as their cofactors. Thus, it seems plausible that the earliest catalysts, at the origin of life, were inorganic elements that were around on the early earth anyway. These inorganic elements by themselves would likely have been much less efficient than when they are a cofactor in an enzyme, but any positive catalytic efficiency would have provided an advantage early on, compared to a background of only spontaneous (i.e., low-rate) reactions. Moreover, many of these inorganic elements would have been able to catalyze multiple reactions. Catalytic specificity probably only arose once proteins were around.[81]

Here, we return to the idea of "nonorganic life," where inorganic elements such as metals mediate across what is nonliving and what is living. The researchers go on to state that such a metallic machine would be able to catalyze the formation of an autocatalytic set, in other words, a network

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[79] Branscomb and Russell, "Turnstile and Bifurcators," 70.
[80] Branscomb and Russell, "Turnstiles and Bifurcators," 73.
[81] Wim Hordijk and and Mike Stee, "Autocatalytic Networks at the Basis of Life's Origin and Organization," *Life* 8 (2018): 62, emphasis added.

of reactions where the products of the reaction become reactants, thereby self-amplifying and stabilizing what could possibly become a chemical circuit.

In the alkaline vent theory of emergence, it is "presumed that proto[-]ferredoxins [proto-iron sulfur proteins] and phosphates were the agencies of energy transfer and expenditure" in the processes working toward cellular life.[82] This is the case because phosphates are thought to be the precursor to ATP (the main "energy currency" of cellular life[83]) and ferredoxins, as iron-sulfur proteins, are adept at donating electrons (principally because of iron's metallic properties), and thus are very useful enzymes.[84] As both ferredoxins and ATP synthases, *as engines*, are able to harness the disequilibrium that exists *at* the boundary of cell membranes, a principle question for origins researchers is how the first proto-ferredoxins and phosphates might have been bound to an ancient proto-membrane for an incipient metabolism to begin. This is because a definite "evolutionary advantage would have been conferred upon those earliest regulated metabolists which developed molecules that bind and stabilize such anions and thereby control the distribution of electrons and protons through the membrane, so enhancing metabolism."[85] A machine able to organize itself into being using these chemical materials could theoretically have a lasting impact on the evolution of life.

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[82] E.J. Milner-White and M.J. Russell, "Sites for Phosphates and Iron-Sulfur Thiolates in the First Membranes: 3 to 6 Residue Anion-Binding Motifs (Nests)," *Origins of Life and Evolution of Biospheres* (2005): 20.
[83] Though it is often understood this way, ATP does not "transfer energy" to power cells. Instead ATP is held in extreme states of disequilibrium by ATP Synthase, and this disequilibrium is harnessed by cellular processes, rather than "energy."
[84] In addition, and returning to a point mentioned above, the existence of proto-ferredoxins at ancient alkaline vents is highly plausible because the iron-sulfur core of these proteins is strikingly similar to the iron sulfur centers of greigite, a geochemical compound found in abundance at vent sites.
[85] Milner-White and Russell, "Sites for Phosphates," 20.

For a long time in molecular biology, it was believed that a protein's three-dimensional structure could be predicted by its amino acid sequence alone. In other words, the way in which a protein folds (which is crucial to its activity) was thought to be predictable in advance. As the field of proteomics continues to grow, it has become increasingly apparent that such a prediction is not possible. Because of this, proteomics remains in a "descriptive mode"—describing current structures of proteins rather than in a predictive mode where a protein's three-dimensional shape may be anticipated in advance, what contemporary scientists require.[86] One recent advance in proteomics that may create the future possibility for protein architecture to be predicted is the discovery of a **"**motif" that is repeatedly found across biological life of a "nest" and an "egg." This maternal metaphor may be able to explain how ancient proto-ferredoxins and phosphates may have secured in proto-membranes.

That is to say that the metallic center of enzymes, according to recent research, are "eggs" that are electrostatically held secure by a "nest." This "motif" is increasingly being found across classes of proteins, especially in ones thought to be ancient.

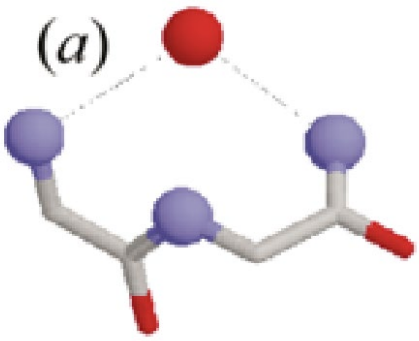

Figure 12: "Nest situations within polypeptides" (Milner-White et al., 2002)

[86] Debnath Pal, Jurgen Suhnel, and Manfred S. Weiss, "New Principles of Protein Structure: Nests, Eggs—and What Next?" *Angew. Chem. Int. Ed*. 41, no. 2 (2002): 4663.

This "nest" motif explains how negatively charged ionic groups are held in place in complex protein architectures. The figure above represents one of the simplest nests. Here, negatively charged anionic groups, or "eggs" (shown above in red), are held in "concave dips" by positively-charged chemical groups. In modern-day ferredoxins and ATP phosphates, this "nesting" motif plays a central role in protein stability. Iron-sulfur complexes and phosphate groups are both negatively charged (or anionic) groups. Iron-sulfur clusters and phosphates groups both *dip* themselves into a concave nest that is held together by the negative charge of the "egg" and the positive charge of the "nests" (represented in the figure above as purple spheres). In relationship to the origins of metabolism, given how central "nests" and "eggs" are to protein architecture, scientists have hypothesized that certain peptides (which are the shorter precursors to proteins) thought to be in abundance at vent sites were able to act as (positively charged) "nests" and sequester (negatively charged) iron-sulphide and phosphates "eggs," thereby securing them to proto-membrane boundaries where an incipient metabolism could begin. Once at the boundary of the proto-membrane, proto-enzymes such as ferredoxins and ATP phosphates act as disequilibrium (or "free energy") converting engines that would capitalize on the chemical and electric thermodynamic tension that exist at this boundary to generate a metabolism that was contingent on the coupling of a dissipation of disequilibrium to an endergonic "uphill" metabolic process.

Here, we return to the idea of "nonorganic life" that—contra DeLanda—does *not* bifurcate metal from organic life. Metals are indeed found at the core of a multitude of enzymes and are key factors in biochemical reactions due to their specific abilities to ceaselessly donate and receive electrons. The "nonorganic life" of metals that flows across life is made possible by the motif of a nest, one that is repeated in proteins all across the domain of life. Metabolism, as the name we give to a whole set of reactions that keep an organism in disequilibrium, is

intimately tied to metallic machines. That the transition metals thought to be in abundance at alkaline vent sites in the Hadean sea are *also* at the active center of proteins that are the most phylogenetically ancient indicate that metals played a crucial role in the beginnings of life. Metal—because of the properties of its "sea" of electrons and its privileged relation to the machinic phylum—brings a specific creative capacity to life, one that continues to enrich and mark life to this day. In the semi-permeable compartmentation of (iron-sulphide) wombs, the first enzymatic (metal-bearing) *engines* would have "naturally" arisen. The birth of proto-metalloproteins here is an organic birth of machines, one that occurs within iron-sulphur wombs that are themselves in disequilibrium.

3.6 Conclusion: A Metabolism Which is Not One

In conclusion, a feminist conceptualization of metabolism, as well as a feminist theorization of "machine," would not be thought through what Irigaray calls a logic of the *one*. Contrary to Hird, metabolism, especially at its origins, cannot be theorized through the "oneness" of equilibrium thermodynamics. Such a paradigm understands metabolism as a series of static states that move from one (preformed, predetermined) state to another through external inputs of energy. It is only *non*equilibrium thermodynamics that can account for the emergence of metabolism itself, and its accompanying self-organizing metabolic machines. Thinking of sexual difference as the engine of life—as the expression of a logic of at least two—can craft a theory of the emergence of metabolism that *does indeed* cut across the binary between nonlife and life (something that Hird attempts to do, but fails to accomplish, with her static idea of "metabolism as ontology").

The origins research I outline in this chapter is largely speculative, which is the nature of this field more broadly. Nonetheless, it is my claim that metabolism, when understood through

*non*equilibrium thermodynamics, abides by a logic of *at least two,* and it is in this way that sexual difference is an *engine* of life. If metabolism cannot be thought as the use, consumption, or transfer of energy, if it instead requires the *conversion of* disequilibria, life—at its origin as well as in its continual development—always exists in relation to a larger "maternal" disequilibrium set on its dissipation. This maternal engine provides a productive tension (through thermodynamic coupling) that life resists, and in doing so, generates new engines that further convert the originary maternal disequilibrium into new forms of disequilibrium that life can directly make use of. It is within this paradigm that a proto-metabolism could have begun.

If there is a reason debates about finalism cannot be erased from biology, it is because goal-directedness and form-taking are intrinsic properties of life.[87] These properties are ones that life borrows from matter and continues to further elaborate in its evolution. If "life is not self-subsistent; yet it is self-producing," it does so with elements that have an intimate relation with the machinic phylum. [88] This self-producing quality of life, an ability that virtually exists in matter, can unfold in relations where disequilibrium can be harnessed using a machinic logic of at least two. Life extends particular qualities of matter throughout its duration, to the point where motifs within proteins continue the theme of nest and egg that began in the origins of metabolism itself. Here, an easy separation between inorganic matter and organic life becomes exceedingly difficult.

Theorizing the genesis of metabolism and the birth of machines without a model of energy transfer requires an altogether different orientation to metabolism's milieu. If a metabolism rooted in sexual difference exists, it is predicated on a logic of at least two that is

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[87] Elizabeth Grosz, "Deleuze, Ruyer, and Becoming Brain," *Parrhesia* (2012) 15: 1-13.
[88] Grosz, "Deleuze, Ruyer, and Becoming Brain," 1.

always in touch with a maternal dissipative drive. This metaphysical orientation and embrace of entropy are the conditions of emergence of a machine that "self" organizes where the machinic parts are not simply externally brought together. Here, machine unhinges itself from mechanism while simultaneously embracing the entities within and through which the inorganic coincides with the organic. Living form that encompasses metabolism as a restless process is created through a maternal engine striving to dissipate itself. A feminist philosophy of life that could address the birth of metabolism would be one that centered on the creative evolution that is made possible through a thermodynamics that desires "to cross thresholds" in order to go "beyond disorder or entropy without discharge."[89]

[89] Irigaray, *An Ethics of Sexual Difference*, 124.

4. The Emergence of Genetics: RNA and The Question of Form

Our present is one where the metaphor of the genome-as-text that can be edited has reached new heights with how genomes are now banked in databases. With the discovery and human biotechnological co-optation of CRISP-cas9—a bacterial-derived enzyme that can recognize and cut genomic sequences in a precise manner—DNA can now be "edited" not only much more cheaply but also much more quickly. This ability to precisely edit is presented as being particularly useful for its medical applications because it may lead to precise altering or deleting of genes associated with life-threatening medical conditions. As Eugene Thacker notes, our contemporary biotechnological moment is one where biology itself has become a technology: "biology is the new medium" rather than the message.[1] The idea of text is being more concretized with contemporary biotechnological advancements.

I want to suggest in this chapter that while the genome-as-text metaphor seems apt for a genome that has already formed, the metaphor of a text that can be edited and altered does not work in the context of the emergence of genetics itself. The beginnings of genetics, the conditions of its emergence, require an altogether different frame of orientation than that given by already existing genomes. It is my aim in this chapter to flesh out the ontological conditions of this biophilosophical event. Like the other chapters of this project, the beginning of genetics is a theoretical question that requires a speculative and ontological approach. In this chapter, I turn to scientific theories that look to the origins of genetics to ask the "basic" question of why did the beginnings of proto-cellular life *invent* genes? What new possibilities does a genome engender for cellular life?

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[1] Eugene Thacker, "What is Biomedia?" *Configurations* 11 (2003): 48.

Before thinking with contemporary origins of life research that theorizes the birth of genetics, I will first provide a short overview of how the gene and genetics are theorized in relation to DNA (deoxyribonucleic acid) in twentieth-century biology. In each section, I will demonstrate what metaphors are at work in each particular understanding of genetics, as well as what questions are possible to ask within each framework, paying particular attention to whether the question of origins and emergence can be asked in each theoretical framing. I then shift my focus to RNA (ribonucleic acid), a nucleic acid that is presented in origins research as being able to reframe the origins of genetics in novel ways. In this research, RNA presents an exciting possibility in the origins of life because it is here that the metaphors of self-formation and self-cleaving become possible. Contemporary research understands RNA to have a kind of self-forming robust liveliness that DNA does not. Following this, I explore the relationship "RNA" is thought to have with the concept of "viral" through how RNA's origins is described by some scientists as being viral-like in nature. I end the chapter with a consideration of how the origins of genetics requires an engagement with the concept of "form." If the rhetoric of DNA is marred with theories about preformationism and a static, spatial, and geometric idea of form—a form that externally arrives to permeate matter—does RNA present the same problems? How might "form" be reimagined to understand origins in a way that does not reproduce gene-centric narratives, and while also opening the possibility for a different, alternative concept of "form," one that is inventive and that dynamically unfolds?

4.1 DNA, The Discourse of the "Gene," and the Impossibility of Form(ation)

In the nineteenth century, Charles Darwin's *The Origins of Species* emphasized how living beings are embedded in time and subject to variation over vast geological periods. While natural selection emphasized change and variability, genetics and the "gene" emphasized the

opposite traits: the hereditary transmission of traits through a kind of constancy.[2] Genetics focused on the question of how the traits within a parent were reproduced and passed onto offspring. Genes were understood as the analogue to the role of the "atom" of nineteenth century chemistry by functioning as a stable unit of selection that grounded the discipline of biology.[3] During the first four decades of the twentieth century, the concept of "gene" existed before DNA's double-helical structure was elucidated and came to be understood as the genetic medium of cellular life forms.

According to historian and philosopher of science Evelyn Fox Keller, the twentieth century inaugurates a split between what becomes the fields of genetics and embryology. After Gregor Mendel's—the "father" of genetics—work on crossbreeding was rediscovered in 1900, a new definition of heredity emerges which "exclusively [refers] to transmission."[4] The beginning of genetics as a discipline understands itself as not being concerned with embryology, the theoretical province where the question of *how* an organism forms itself exists (a question that I will return to at the end of this chapter). Genetics, argues Keller, "had no answer to how a single germ cell might produce an organism."[5] This is because genetics was thought to lie in the cellular domain of the nucleus, the "control" center of a cell, while embryology took place in the cytoplasm of cells.[6]

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[2] Evelyn Fox Keller, *The Century of the Gene* (Cambridge, Massachusetts: Harvard University Press, 2000), 13.
[3] Keller, *The Century of the Gene*, 19.
[4] Keller, *Refiguring Life: Metaphors of Twentieth-Century Biology* (New York: Columbia University Press, 1995), 2.
[5] Keller, *Refiguring Life*, 6.
[6] Bonnie Spanier, a molecular Biologist and feminist, argues that "genderization has permeated the field of cellular biology and has been superimposed onto parts of cells" ("Gender and Ideology in Science: A Study of Molecular Biology," *NWSA Journal* 3, no. 2 (1991): 177.

Within the nucleus, genes became the basis of life through what Keller calls "the discourse of gene action." The idea of "gene action" inaugurated what genes did before there was scientific research to support these claims. Genes were understood be active. This kind of self-proclamation produced the effects that were preemptively argued to exist.[7] On this, Keller notes how gene action coincided with casual agency:

> ...geneticists between the mid 1920s and the 1960s referred to the 'causal processes' that connect the gene and the characters, and it was a way of talking that at least tacitly granted to the genes the power to act, even in the absence of any information about *how* they might act. This same way of talking endowed the gene with a most curious constellation of properties. At one and the same time, the gene was bestowed with the properties of materiality, agency, life, and mind.[8]

Endowed with mind, the gene had (or was assumed to have) not only a vitalist quality but also "the ability to plan and delegate."[9] Keller argues that the attribution of gene action actually worked to obfuscate the question of *how* genes act. Furthermore, during the time period of "classical genetics" the model organisms of the *Drosophila* fly and corn maize allowed genetics to refine its experimental techniques while also sedimenting the idea that "with the gene comes life."[10]

The tension between and separation of genetics and embryology is felt in contemporary origins research regarding the origins of genetics. Genetics is a field that continues to be best suited to the "study only variations in already existing organisms."[11] The question of the formation of an organism is perhaps still outside the field's theoretical apprehension. In my view, the emergence of genetics needs to be reunited with the question of formation in a way that

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[7] Keller, *Refiguring Life*, 10.
[8] Keller, *The Century of the Gene*, 46.
[9] Keller, *The Century of the Gene*, 47.
[10] Keller, *Refiguring Life*, 9.
[11] Keller, *Refiguring Life*, 13.

addresses the reality of genetics but does not conflate the *origins* of cellular life with genetics. There are two main reasons for this. First, as chapters two and three demonstrate, semipermeable compartmentation and an incipient metabolism must first be generated for genetics to begin. To quote Martin and Russell, "no nucleic acid evolution is possible without a supporting geochemistry, later biogeochemistry and finally biochemistry to provide a steady flow of adequate concentrations of polymerizeable precursors (for example nucleotides) and thus to underpin any sort of replication."[12] A supporting biochemistry is another name for metabolism. As I discussed in chapter two, the emergence of genetics requires that the "concentration problem" be solved: organic precursors of nucleic acids need to be in close proximity with one another to further react and complexify in order bring about an RNA world—in short, they need semipermeable compartmentation, what we could also call inorganic wombs. The chemical reactions that would systematically build the required complexity for a primordial genetics to begin require disequilibrium to drive them into being—in other words, they need a preexisting metabolism. The second reason the emergence of genetics needs to be reunited with the question of formation in a way that addresses the reality of genetics but does *not* conflate the *origins* of cellular life with genetics is because a concept of form that is *not* rooted in preformationism (the hallmark of how form is often understood in the history of genetics) can reorient how we understand the relation between inorganic matter and organic life in a way that addresses what life shares with matter. Such a theoretical remaking of form can be developed by meditating on scientific research, but ultimately requires a philosophical framing that science itself cannot address because the findings cease to be empirical. Before doing this, however, an overview of how RNA might provide an alternative metaphorics for the beginning of genetics is necessary.

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[12] Martin and Russell, "On the origins of cells," 64.

4.2 Why RNA? The Desire for Self-Replication

Speculations on RNA's possible role in the beginnings of genetics date back to the 1960s.[13] Francis Crick, one of the three scientists awarded the Nobel Prize for elucidating the structure of DNA, is credited with gesturing toward the possibility of RNA world.[14] In a 1968 paper, he proposed that "possibly the first 'enzyme' was an RNA molecule with RNA replicase properties."[15] The RNA world was formally coined as such by physicist and molecular biologist Walter Gilbert in 1986.[16] It describes a hypothetical scenario deep in the origins of life before the time of DNA. DNA is an inert molecule that is largely nonreactive. While this makes it particularly adept at storing information, scientists do not view DNA as robust enough for the origins of replication.[17] One particular reason relates to what is termed the "central dogma" of molecular biology. Coined by Francis Crick in 1958, the central dogma expresses the unilateral transfer of genetic information in a cell that moves from DNA to RNA to protein.[18] This is the

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[13]See Leslie Orgel, "Evolution of the genetic apparatus," *Journal of Molecular Biology* 38, no. (1968): 381-393; Carl Woese. *The genetic code: The molecular basis for genetic expression* (New York: Harper and Row, 1968), and Francis Crick. "The origin of the genetic code," *Journal of Molecular Biology* 38: 367–379.

[14] Francis Crick, John Watson, and Maurice Wilkin were awarded the Nobel Prize in Physiology or Medicine in 1962. Their elucidation of DNA's structure was made possible by Rosalind Franklin's X-ray crystallography research. Franklin's role in this endeavor was recognized after her death. See Branda Maddox, Brenda, *Rosalind Franklin: The Dark Lady of DNA*, London: (Harper Collins, 2013).

[15] Crick. "The origin of the genetic code," *Journal of Molecular Biology* 38(1968): 367–379.

[16] Walter Gilbert, "Origin of Life: The RNA World," *Nature* 319 (1986): 618.

[17] Following the end of World War II, the influence of cybernetics on biology resulted in *inheritance* to be understood using the concept of *information*. Because information at this time was formulated in a way that erased its relation to materiality, inheritance-as-information resulted in the concept of the gene to be "abstracted away from its physical basis and characterized in purely [immaterial] informational terms" (John S. Wilkins and Pierrick Bourrat, "Replication and Reproduction," *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, https://plato.stanford.edu/archives/sum2019/entries/replication.). See also Richard Doyle, *On Beyond Living: Rhetorical Transformations in the Life Sciences* (Stanford: Stanford University Press, 1997).

[18] Francis Crick, "On protein synthesis," *Symp Soc Exp Biol* 12 (1958):138–163.

case because all cellular life forms require that RNA transcribe DNA's "code," and then connect this transcription into the translation of proteins.[19] A theory in search of the origins of genetics seeks a molecule that is hypothetically capable of self-replicating, thereby solving the dilemma of the chicken-or-egg. In microscopic terms, the chicken-or-egg conundrum consists in how DNA needs proteins for its expression and proteins require DNA in order to be translated. From a modern cellular perspective, which exclusively utilizes DNA for genetic storage, the system appears to be in a gridlock in relation to the emergence of genetics. From the vantage point of DNA, we are at a standstill as to how such a system, which works with accuracy in the contemporary biological landscape, could have come into being.

DNA's support structure is a repeating sugar-phosphate backbone. This sugar-phosphate is not where the "information" embedded in DNA exists. The informational aspect of DNA resides in its nucleotide sequences. Each DNA nucleotide can either be an adenine (A), thymine (T), guanine (G), or cysteine (C) nucleotide. These nucleotides link together in a systematic manner (A-T and G-C) inside DNA's sugar-phosphate backbone. If one were to understand DNA from an informational standpoint using the framework of Claude Shannon's theory of

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[19] In a 1958 paper, Crick argues that information in the context of the central dogma refers to "the *precise* determination of sequence, either of bases in the nucleic acid or of amino acid residues in the protein" (Crick, "On protein synthesis, 153, emphasis in original). Crick posits that information can pass from DNA to RNA, but *also* back from RNA to DNA. Information *cannot*, however, travel "back out" once when it becomes a protein: "'information' has passed into protein *it cannot get out again*. In more detail, the transfer of information from nucleic acid to nucleic acid, or from nucleic acid to protein may be possible, but transfer from protein to protein, or from protein to nucleic acid is impossible" (153). Thus, it should be noted that information traveling "backwards" from RNA to DNA is *theoretically plausible* for Crick. His original formulation is more complex than how the Central Dogma is usually presented. James Watson put forth a more restrictive conceptualization of the central dogma in a 1965 text, in which he argued that there is unilateral flow of information from DNA to RNA (James D. Watson, *Molecular Biology of the Gene* (New York: W. A. Benjamin, Inc., 1965).

information, there is a possibility of four nucleotide bases for each position in this sequential code, or 4^1 possibilities per nucleotide position. While this idea of information may hold for a very short nucleic acid chain, in a biological context it quickly becomes untenable: "in the context of a relatively short polypeptide consisting of 50 amino acids, a corresponding 150 nucleotide sequence of DNA codes for a quantity of Shannon information (4^{150} or $\sim 2\times 10^{90}$) that exceeds the number of atoms perceived to exist in the entire physical universe ($\sim 10^{80}$)."[20] Information without meaning does not cohere in the biological sphere. Information, as I will detail below in relation to the *in vitro* evolution of viral RNA, only becomes relevant through a larger system in which it is embedded.

In the context of Shannon information, RNA, which is also comprised of 4 nucleotide bases (except that instead of thymine it consists of uracil [U]), carries the same "amount" of information in terms of each nucleotide possibility. That being said, RNA's relationship to the concept of information differs from DNA due to its different three-dimensional structures. Unlike DNA's double helical structure, RNA has a single-stranded composition. This makes its relationship to structure and function vastly differ from DNA. RNA's single-stranded structure allows it to spontaneously fold back on itself and form a vast variety of spatiotemporal structures. These structures embody "a unique relationship between sequence and structure not utilized by DNA."[21] If structure and function are intertwined in a biological context, DNA's structure provides it with a certain stability that allows it to store information exceptionally well. RNA, in contrast, is less adept at storing information (though it can do that as well to an extent). Because

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[20] Wade W. Grabow and Grace E. Andrews, "On the nature and origin of biological information: the curious case of RNA," *Biosystems* 185 (2019): 104031.
[21] Grabow and Andrews, "On the nature and origin of biological information," *Biosystems* 185 (2019): 104031.

of its vast array of three-dimensional spatiotemporal structures, however, RNA excels at performing a multitude of cellular functions. This arguably places RNA in closer proximity with proteins, which also form a variety of three-dimensional forms that are intimately aligned with their functional capabilities. RNA, however is much easier to generate *de novo* than proteins.

Scientific research on a possible RNA world is rooted in the desire to find an agent that can self-replicate by copying, polymerizing, cleaving itself to initiate a minimal genetic system. In such a hypothetical RNA world, self-sustained replication is the most privileged attribute. Gerald Joyce, a pioneer in the field of *in vitro* evolution, has explored this kernel of thought in his career from the 1980s to the present. Simply put, *in vitro* evolution is human-directed evolution that occurs outside of a living cell in controlled laboratory conditions. As postulated by Crick, the RNA world hinges on the idea of a strand of RNA that itself was a replicase enzyme and that therefore could bring out its own replication. This is a desire for an RNA molecule that not only self-generates but that can also produce nucleotide progeny.

The metaphors of self-expression and propagation that surround DNA deny how it requires a whole host of intracellular entities to be transcribed and translated. In contrast, metaphors that surround the potential evolutionary capabilities of RNA—which revolve around notions of self-generation, self-touching, and self-cleaving—are much more scientifically accurate in that they reflect RNA's actual morphogenetic abilities. RNA in early molecular evolution is positioned as an agent capable of both self-replication and information storage, both genotype and phenotype because of its three-dimensional structures. Signs of an RNA world in contemporary biological organisms indeed gesture toward some form of an ancient RNA world.

4.3 Signs of an RNA World: Splicing and Ribozymes

There are a few central "smoking gun" scientific discoveries that support the idea of a primordial RNA world. Up until the 1980s, it was assumed in molecular biology that only proteins could function as catalytic enzymes. It was in the early 1980s when Thomas Cech, a professor of chemistry at the University of Colorado Boulder, discovered a peculiar property of RNA. Cech was initially studying transcription, the copying of DNA into RNA, of a large ribosomal RNA precursor in a single-celled pond animal called *Tetrahymena thermophila*. At this time, Cech's lab had found that during the transcription of this gene, RNA splicing (i.e., the cutting of the RNA strand) was taking place outside of the cell, *in vitro*, with purified extracted RNA. This was odd, because there were presumably no proteins in the experiment to perform this cleaving. Using this as an opportunity to investigate the mechanism of RNA splicing (i.e., how RNA strands are cut), Cech decided to redesign the experiment by removing the molecules necessary for transcription. The very precise way the introns, or noncoding segments of DNA, were being removed and recombined from a stretch of DNA suggested that there was a protein contaminant in the experiment. After multiple laboratory techniques of removing or "washing" away the protein with a chemical detergent, the splicing reaction still took place. This resulted in the modified hypothesis that perhaps RNA itself was responsible for the splicing reaction.

This idea was confirmed when an artificially constructed RNA, one that had never been inside *Tetrahymena* and thus could not be contaminated with a possible protein, resulted in the splicing reaction.[22] A similar experiment that showed the catalytic properties of RNA occurred in 1989 at Sidney Altman's Lab at Yale. There, an enzyme called RNaseP had catalytic properties

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[22] "Tom Cech (University of Colorado, Boulder/HHMI): Discovering Ribozymes." https://www.youtube.com/watch?v=WAChisSiW3o

that "cleaves tRNA precursors to generate mature 5' termini."[23] Altman's lab specifically stressed that the catalytic property of rRNaseP resided in the RNA component of the enzyme. Cech's and Altman's experiments together confirmed that RNA has vastly different capabilities than DNA. Since then, entire catalogues now exist that document the enzymatic properties of RNA (which is a property that DNA lacks). This particular nucleic acid exists at the periphery of being an informational and a catalytic entity. Cech and Altman were jointly awarded the Nobel Prize in Chemistry in 1989 for these discoveries.

The active capabilities of RNA that exceed the inertness of DNA became clear again in relation to the chemical architecture of enzymatic machines known as ribosomes. A ribosome is "a micro-machine for manufacturing proteins."[24] In the bioarchitecture of modern-day cells, ribosomes perform the crucial function of building proteins by stringing together amino acids using a messenger RNA (mRNA) template. Ribosomes "read" mRNA and choose corresponding amino acids to form the primary structure of proteins. After further folding into secondary, tertiary and quaternary structure, biological proteins are formed. In the previous century, the ribosome itself was thought to be a highly complex set of proteins. In 2000, a scientific article declared, using an atomic resolution rendering of the subunit of ribosome, that the portion of the ribosome responsible for peptide bond formation had an interior active site that was primarily made of RNA.[25] The active site was surrounded by a multitude of proteins, but the site of peptide synthesis was RNA itself.

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[23] S.Altman, M.F.Baer, M.Bartkiewicz, H.Gold, C.Guerrier-Takada, L.A.Kirsebom, N.Lumelsky and K.Peck, "Catalysis by the RNA subunit of RNaseP-a minireview," *Gene* 82 (1989): 63-64.
[24] British Society for Cell Biology, "Ribosome," https://bscb.org/learning-resources/softcell-e-learning/ribosome/, accessed January 10, 2020.
[25] Nenad Ban, Poul Nissen, Jeffrey Hansen, Peter B. Moore, Thomas A. Steitz, "The Complete Atomic Structure of the Large Ribosomal Subunit at 2.4 Å Resolution," *Science* 289, no. 5481 (11Aug 2000): 905-920

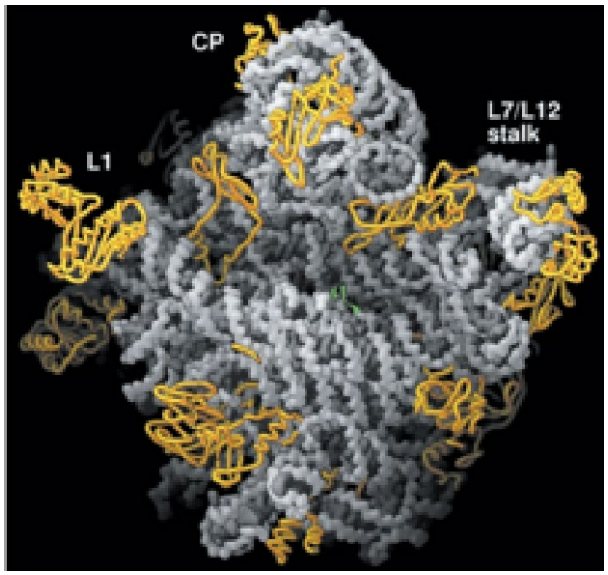

Figure 13: The large ribosomal subunit of *H. marismortui.* The gray components are RNA

This RNA active site in the ribosome's center is highly conserved across genetic lineages. That the most crucial protein making sites in cellular bodies have an RNA catalytic center strongly supports the idea that there once existed some kind of RNA world that preceded protein catalysis. This scientific discovery prompted Cech to declare that the ribosome is in fact a ribo*zyme*, signaling that molecular agents we thought to be exclusively proteins actually are partially composed of RNA. On this speculation, Cech notes:

> Why does nature use RNA catalysis to achieve protein synthesis? One argument is evolutionary. If, indeed, there was an early RNA world where RNA provided both genetic information and catalytic function, then the earliest protein synthesis would have had to be catalyzed by RNA. Later, the RNA-only ribosome/ribozyme may have been embellished with additional proteins; yet, its heart of RNA functioned sufficiently well that it was never replaced by a protein catalyst.[26]

[26] Thomas R. Cech, "The Ribosome is a Ribozyme," *Science* 289, no. 5481 (11 Aug 2000): 879.

That the *ribosome* is in fact a *ribozyme*—in other words, that the central cell organelle that produces proteins has *RNA* at its active center, rather than a protein—resulted in a paradigm shift in how we understand core cellular processes to operate. It suggests that cellular components contain a memory of ancient events that can be inferred from a top-down perspective. That being said, though one can glean an RNA world from a top down perspective of modern-day ribozyme structure, the question of how to experimentally reconstruct an RNA world from a bottom-up perspective is much more difficult, and, as I will detail below, as of yet, not possible. Is this impossibility simple a deficiency of current scientific experimental methods? Or, does it gesture towards a different metaphysical problem that relates to biological formation?

4.4 In Vitro Evolution and "Self"-Replication of Viral RNA

RNA can indeed splice itself and the ribosome is actually a ribozyme. That being said, what clues does this give us about the origins of RNA replication itself? Can RNA actually "self"-replicate? One class of experiments that highlight the scientific fascination and use of RNA is *in vitro* evolution, or evolution that occurs outside of a living cell in controlled laboratory conditions. Artificial selection is akin in many ways to *in vitro* evolution. This experimental modality involves the human-directed evolution of nucleotides or enzymes through the selection of a particular quality or function of a molecule. One famous experiment that demonstrates the *in vitro* evolution of viral RNA is colloquially known as "Spiegelman's Monster." Conducted in Sol Spiegelman's lab at the University of Illinois Urbana-Champaign in the early 1970s, the initial goal of this experiment was to assess whether an isolated bacterial viral enzyme from a bacterial virus that infects *E. coli,* Qß phage, could synthesize a "biologically competent and infectious

viral RNA."[27] In other words, can cellular processes that occur outside a biological milieu retain their biogenic ability to infect? Outside the body of *E. coli,* the enzyme Qß was able to synthesize novel RNA phage in the test tube. When reinserted into an *E. coli* cell, the viral RNA still had the ability to cause infection. Thus Spiegelman's first experiment confirmed his hypothesis.

After these results were achieved, Spiegelman conducted a follow-up experiment that studied chemical evolution in a test tube. An RNA derived genome underwent natural selection outside of a living body. In a test tube that contained viral Qß phage RNA, the enzyme RNA replicase, and salts, RNA replication took place. From here, the experiment selected for RNA molecules that self-replicated the fastest. The RNAs that were most successful in completing this task were continuously transferred to new test tubes via serial dilutions which were also enriched with RNA replicase and nutrients. Because the selective pressure solely favored fastest replication through each serial dilution, the most successful replicating viral RNAs successively shortened their sequences through each serial transfer. This resulted in them losing almost all genetic information that did not relate to the binding of RNA replicase. While the initial Qß phage had 3600 nucleotides, the RNA phage at the end of the experiment possessed only 218. Spiegelman's lab argued that "these findings provided the first opportunity to perform extracellular Darwinian experiments on replicating nucleic-acid molecules under conditions that simulate certain aspects of precellular evolution, where environmental discrimination operated at the level of the gene rather than the gene product."[28]

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[27]D. L. Kacian, D. R. Mills, F. R. Kramer, and S. Spiegelman, "A Replicating RNA Molecule Suitable for a Detailed Analysis of Extracellular Evolution and Replication," *Proc Natl Acad Sci U S A*. 69, no. 10 (1972): 3038–3042.
[28] Kacian et al., "A Replicating RNA Molecule," *Proc Natl Acad Sci U S A*. 69, no. 10 (1972): 3038.

This experiment is colloquially termed "Spiegelman's Monster" because it exhibits *in vitro* evolution of nucleic acid derived from an RNA virus. Though evolution is being observed here through serial dilution, it is disingenuous to call the RNAs created through Spiegelman's experiment "self"-replicating. The Qß bacteriophage could not replicate without its enzyme RNA replicase. Because the serial transfer of RNA only favored the RNA particles that replicated the fastest, over time the RNA genome of the bacteriophage vastly shortened. While Spiegelman's initial experimental goal was to prove that "the newly synthesized RNA is fully competent" in its ability to infect "as the original viral RNA,"[29] in the second experiment, the virality of the RNA was lost. The selective pressure resulted in the phage RNA deleting almost all genomic sequences not involved in the binding with its replicase (such as entering its *E. coli* host). While this experiment demonstrates a kind of *in vitro* evolution, it does so in a negative way.

Instead of gaining complexity, without the context of a body, "the viral genome has nothing to account for beyond its own self-replication."[30] In other words, it did not result in an increase in informational complexity. We can instead understand this experiment as a case of *devolution*. On this, one commentator reminds us that evolution *without context* cannot increase in informational complexity:

> There is no inherent information-generating quality to molecular evolution, any more than there is to biological evolution. Information only evolves in the context of utilization. If this context is just replicative effectiveness of RNA strands, there is no selective ground for accumulating other kinds of information. Information for making functional proteins is burdensome for bare replicators. It is selected in nucleic acids only in contexts where replication requires the participation to whose operation it is relevant. The strategy of parasitic devolution, the mode of evolution that prevails when essential nutrients are provided *gratis* by nature or by experiment, is to pare down to minimum

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[29] S. Spiegelman, I. Haruna, B. Holland, G. Beaureau, and D. Mills, "The Synthesis of a Self-Propagating and Infectious Nucleic Acid with a Purified Enzyme," *Proc Natl Acad Sci USA* 53, no.3 (1965): 927.
[30] Jeffrey S. Wicken, *Evolution, Thermodynamics, and Information: Extending the Darwinian Program* (Oxford: Oxford University Press, 1987), 103.

> genotypic information. The generative of this devolutionary tendency is shown by the great selective advantages that accrue to microbial mutants that lose biosynthetic functions in compensating growth media. The evolutionary genesis and stabilization of genetic information requires that it have a functional referent to which it is useful.[31]

Without the context of a proto-organismic whole, RNA generates less genomic complexity. If genetics began in a proto-RNA world, it could not have occurred in the context of RNA without a body solely focused on "self"-replication. A "bare replicator," even when it is RNA, cannot produce even a "simple" genetic system.[32]

In vitro RNA experiments point to the usefulness, as well as the limits, of experimental research on this nucleic acid. Gerald Joyce, a professor at the Salk Institute for Biological Studies, has focused on this problem for much of his career. In a 1987 experiment in his lab, an enzyme called Class 1 RNA ligase was "challenged to attach an oligonucleotide substrate to the 5' end of the RNA."[33] In other words, the experiment tested whether RNA could lengthen a nucleotide on a particular strand of an RNA base, an activity that is precisely done *in vivo*. Within the test tube, an RNA enzyme from a bacteriophage virus called T7 RNA polymerase was included. T7 bacteriophage generated copies of RNA enzymes from DNA for the reaction. This resulted in an amplification of ligated (or longer) RNA nucleic strands. Though the initial aim of this reaction was achieved, for Joyce, this reaction does not fulfill Crick's and his desire for an RNA that could

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[31] Wicken, *Evolution, Thermodynamics, and Information*, 104.

[32] Richard Dawkins formulated the notion of a "replicator" in *The Selfish Gene*. Drawing inspiration from Weismann's idea about the continuity of germ-plasm, Dawkins argues that evolution ultimately acts on the gene, which for him is the "fundamental unit of selection" (*The Selfish Gene,* Oxford: Oxford University Press, 1989, 11). DNA molecules are replicators. Replicators use "survival machines" or vehicles—like the body—to propagate themselves (254). A "bare replicator," then, is the idea that the vehicle can be completely done away with in evolution.

[33] Gerald F. Joyce, "Evolution in an RNA World," *Cold Spring Harb Symp Quant Biol*. 74 (2009): 18.

replicate itself. This is because the experiment uses enzymes derived from a bacteriophage to generate RNA. Because both of these enzymes "are the products of biological evolution," this reaction, despite demonstrating the lengthening of the RNA strand, still does not fulfill genuine RNA self-replication and catalysis. Despite this drawback, the scientific desire to try to find an RNA enzyme that could catalyze its own self replication did not stop with this experiment.

Another experiment consisted in a particular RNA ligase enzyme called "R3C" RNA enzyme, which was constructed using *in vitro* evolution and selection.[34] This enzyme was selected to join two separate RNA substrates. When the RNA substrates were joined, they created another form of R3C, which could be interpreted as the "self-replication of an RNA enzyme.[35] This task was achieved after a series of replications and serial dilutions. When postulating on whether this artificial genetic system is alive, Joyce provides a firm answer:

> No. The artificial genetic system based on RNA enzymes that catalyze their own replication has many of the properties of a living system, but lacks the ability to bring about *inventive* Darwinian evolution. The molecules can undergo self-sustained replication with exponential growth. "Self-sustained" in this context refers to their ability to operate without the aid of an external catalyst. All of the genetic information that is necessary for the system to replicate and evolve is part of the system that is undergoing replication and evolution.[36]

Joyce's thoughts on the second experiment concerning "R3C" RNA enzyme are in a similar vein. While this experiment is an example of evolutionary adaptation, Joyce argues that this system is also not alive. The reason for this is that the system does not invent new forms. *In vitro* evolution, while it demonstrates Darwinian evolution (i.e., that generation of new traits), begins with

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[34] Ligase enzymes etymologically derive their name from the Latin verb *ligāre*, which means "to bind" or "to tie together," and *–ase*, the scientific suffix that denotes enzymes. Ligases catalyze the joining together of chemical molecules.
[35] Joyce, "Evolution in an RNA World," 18.
[36] Joyce, "Evolution in an RNA World," 18, emphasis added.

biochemical structures "borrowed" from the domain of biology. Joyce's second experiment concerning "R3C" RNA enzyme that resulted in the mutual "self-replication" of two RNA enzymatic strands also does not qualify as being evolutionarily inventive:

> There are evolved entities still lurking behind the curtain — not polymerase enzymes borrowed from biology, but the R3C catalytic motif and various aptamer motifs that were obtained by directed evolution conducted outside the system. Once placed within the synthetic genetic system these preexisting motifs can be further evolved, but how could functional motifs [themselves] be invented within the system?
>
> A living system must not only be capable of undergoing Darwinian evolution in self-sustained manner, but also have a broad *inventive* capability that enables the discovery of adaptive solutions to a variety of challenges imposed by the environment.[37]

Joyce reminds us that the construction through the directed evolution of R3C ligase was produced through a prior experiment. The particular three-dimensional structure of the specific 'motifs' of its folds that resulted in the construction of its catalytic properties were externally derived and painstakingly created through a series of step-by-step reactions. Thus, this experiment purportedly demonstrated RNA self-replication, but only through a series of separate, step-by-step processes.

There is a difference between *in vitro* and *in vivo* evolution, and it revolves around the activity of invention. *In vitro* evolution, like artificial selection more broadly, selects for a particular desirable trait through successive replications. While *in vitro* experiments can focus in on a particular trait of an enzyme and further hone and modify this trait, they are incapable of inventing biological forms in and of themselves. *In vitro* experimentations, even when partitioned into a series of small experiments for each step, cannot generate RNA enzymes *de novo* in the same experiment that tests for self-replicating abilities. This is because the RNA enzymes either

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[37] Joyce, "Evolution in an RNA World," 17, emphasis added.

come from cellular organisms or viruses. Or, alternatively, the experiments need to "borrow" pre-existing RNA folded motifs (that is, three-dimensional structures with catalytic properties) through precise trial-and-error methods *before* the experiment testing for self-replication occurs. Joyce continues along this thread:

> A living system must not only be capable of undergoing Darwinian evolution in a self-sustained manner, but also have a broad inventive capability that enables the discovery of adaptive solutions to a variety of challenges imposed by the environment.[38]

In vitro experiments can demonstrate evolutionary adaptation, but not evolutionary invention. The domain of invention demands the generation of new, hitherto unexpected forms that subsequently continue to evolve. Morphogenesis first hinges on a primary inventive ability to create such forms. It is this ability to invent that *in vitro* RNA experiments fail to create.

The question that such experiments do not address is whether the birth of RNA occurred in a piecemeal format as is the case in directed evolution. What remains impossible within such considerations of self-replication is *how* such a process would begin and act as a whole. What is it about the origins of proto-life that generated self-replication? How can a particular entity make itself? Can *in vitro* nucleic-centric research, even when it is RNA centric, explain genetic emergence? Below, I will suggest that if an RNA world requires genuine invention, this can only occur through an engagement with embodiment that creates the conditions for the invention of form.

4.5 RNA as Viral-like: Genetics and A Logic of Contagion

An alternative way to address the possibility of an RNA world utilizes a different combination of a top-down and bottom-up perspective. This outlook takes the environmental

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[38] Joyce, "Evolution in an RNA World," 23.

milieu into account in an important way. The origins of genetics must rethink the paradigm that the cell is the smallest unit of life. In line with the alkaline vent theory I have explored in previous chapters, some researchers address the birth of genetic systems in an intimate and necessary relation with inorganic compartmentation. In contemporary origins research, the last universal common ancestor (LUCA) that gave way to the oldest domains of cellular life, is overwhelmingly understood as a non-free living organism. In other words, LUCA is thought to have been a large inorganic consortium that housed emerging life rather than a fully-fledged autonomous cell. This speculative starting point emphasizes that life would need to be materially homed (in an inorganic womb) in order to begin. This then presents a theory of informational birth that requires a pre-existing body. Remembering that genetic material itself is not alive, even in the case of catalytic RNA which is also a kind of informational storage produced by life, LUCA as a non-free living organism—one that is homed in an inorganic womb or milieu—avoids reproducing the issue of information losing its body.[39] In addition, an inorganically housed LUCA provides the material conditions for proto-biological *invention* to occur. This mode of self-making still places RNA at its center, but this time in relationship with liminally alive entities that adopt viral-like strategies.

In vitro experiments of evolution demonstrate the crucial importance of an organismic body for evolution. In an article called "On the origin of genomes and cells within inorganic compartments," Eugene V. Koonin and William Martin argue that LUCA was housed within inorganically confined iron-sulfide (FeS) compartments. Within these spaces, the origins of genomes consisted of "populations of virus-like RNA molecules, which eventually encoded one

[39] N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 1999).

or a few proteins each, [which subsequently] became the agents of both variation and selection."[40] Here, the birth of RNA is theorized is thought to have been "viral-like."

The term viral-like suggests that strategies witnessed in something related to viruses embody the birth of genetics itself. If viruses are not "alive" outside of a living material body, within the home of inorganically confined LUCA, viral-like replicators point toward how, with embodiment, a theme or an orientation – so instead begins to unfold that can *invent* new forms. I want to suggest here that "viral-like" strategies follow this orientation of life to evolve. This allows for the relationship between living beings, the rise of genetics, and the concept of form to be addressed, and can therefore potentially work as an antidote to contemporary origins research that avoids the philosophical question of how form relates to life. By avoiding addressing the question of form, origins research solely focuses instead on the material products of evolution. Moreover, and as seen in *in vitro* evolution, origins research focused on RNA evolution must begin with nucleic acids or motifs that are provided by biology itself, and therefore is still unable to invent new forms purely "from scratch." The closest research comes to thinking about RNA and the question of form is when viruses or viral-like strategies within evolution are discussed. However, viruses as "inventors" of novel genes are often presented in scare quotes in scientific literature. This, however, is at odds with how "viral" both points towards a continuity of life between the beginnings of "non" free-living life of LUCA and cellular life. Perhaps the origins of genetics unfolds a logic of becoming-viral. If this is the case, what is the relationship between RNA and virality?

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[40] Eugene V. Koonin and William Martin, "On the origin of genomes and cells within inorganic compartments," *TRENDS in Genetics* 21, no. 12 (December 2005): 647.

While all cellular life uses double-stranded DNA as its mode of genetic replication, viruses and viral-like entities are biological agents that utilize a vast repertoire of genetic systems. There are single-stranded RNA and double-stranded RNA as well as single and double stranded DNA viruses. This diverse range of genetic replication systems contrast with the DNA replication of cells. Viruses (and viral-like entities) have explored the logic of replication more so than cells, which suggests that they perhaps have a much more intimate relation to genetics than DNA replication in cellular life.[41]

Returning to Koonin and Martin's proposal that the origins of genetics coincided with viral-like strategies within inorganic compartments, this conceptualization is possible when the definition of viruses as "runaway genes" or parasites derived from cellular life is no longer in place. If viruses are ancient entities that predate the birth of cellular life, they can no longer be simply thought of as "obligate intracellular parasites."[42] Luis Villarreal, a virologist at The University of California-Irvine, destabilizes the dependence of viruses on cells through a redefinition of virus. Rather than classifying them as "obligate intracellular parasites," he simply defines viruses as "molecular genetic parasites."[43] The former makes it conceptually impossible for viruses to exist without cells already being present. The latter treats the cell as a particular product of more ancient (and more unstable) replication systems. Viruses, when defined as molecular genetic parasites, can coexist with these earlier evolutionary replication systems. Thus those earlier replication systems predate what we define as the smallest unit of life in contemporary science—the cell. In this shift, it becomes possible for viruses to be parasites of the

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[41] Though not my focus here, there is abundant research that suggests that viruses continue to invent new genes in cellular life.
[42] Luis P. Villarreal, *Viruses and the Evolution of Life* (Washington, DC: American Society for Microbiology Press 2005), 8.
[43] Villarreal, *Viruses*, 8.

"prebiotic, acellular replicating systems" that predated cellular life.[44] As *molecular genetic* parasites, viruses "are capable of parasitizing any replication system, including other viruses as well as prebiotic systems. Thus, there is a reason to think that even prior to cellular life forms, molecular genetic parasites may have already existed."[45] In taking into account invention as a central feature, viruses present the possibility of being key agents in the origins of genetics. One can perhaps go one step further than Villarreal and suggest that viruses are not just parasites of a replicating system, but perhaps invent such systems themselves.

Viral-like logic and evolutionary invention perhaps do not even begin with fully-fledged viruses. Viroids are very small infectious entities (even smaller than viruses) with noncoding RNA's (which is RNA that does not code for a protein and instead replicates itself). This makes them evolutionarily distinct from viruses. While a virus is a parasite that uses a cellular host's translational machinery to generate the production of viral proteins to self-replicate, a viroid, in contrast, uses a host's *transcriptional* machinery. The transcriptional machinery primarily refers to the enzyme RNA polymerase, which in a un-infected cell copies DNA into RNA. Viroids use RNA polymerase to generate further single stranded RNA copies of themselves. The presence of viroids demonstrates a logic of contagion that seems to accompany all fundamental cellular process, even transcription (the genetic process that produces RNA). It seems as if every genetic invention in the history of life has a contagious partner, or rather comes into being *through* contagion. Some relics of creative contagion still presently exist.

From a top-down perspective, there are a few clues that suggest viroids are ancient relics of an RNA world. First, at this time, viroids are the smallest known replicating agents.

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[44] Villarreal, *Viruses*, 8.
[45] Villarreal, *Viruses*, 8.

Furthermore, they are primarily made of the linked nitrogenous base pairings of guanine and cytosine. This particular base pairing, which forms the backbone of an RNA molecule, consists of three hydrogen bonds. This makes G-C bonds more thermodynamically stable than the alternate base pairs of adenine and thymine, which only have two hydrogen bonds.[46] In addition, viroids replicate through a logic of "circularity" rather than a linear sequence of replication. This allows them to not need specific nucleic sites that instruct where replication should start and stop, something that is required in the replication of a linear strand of nucleic acid. Most importantly, because they only utilize the transcriptional machinery of a cell, viroids replicate without requiring the encoding of proteins.[47] Because this latter process is linked to ribosomes, viroids are hypothesized to have been operating in the "first" portion of the RNA world that predated ribosome-generated proteins (and proteins more broadly). Lastly, some viroids display catalytic activity via a particular kind of ribozymes known as hammerhead ribozymes, which is perhaps the most desired quality of a biological entity thought to be from the RNA world.

Although viroid RNA polymerization has not been witnessed *in vivo, in vitro* evolution demonstrates that RNA enzymes can "undergo self-sustained replication in the absence of proteins."[48] This case of *in vitro* evolution differs from Spiegelman's monster, in which a protein enzyme was involved in the replication of viral RNA. This combinatory approach of *in vitro* and *in vivo* experiments piece together the scientific desire for RNA to be able to self-replicate. Scientific research stresses the physicochemical continuity of life, without addressing what the philosophical implications of this continuity might be. How can we move from the "inorganic" to

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[46] Selma Gago-Zachert, Pedro Serra, Rafael Sanjuan, and Santiago F. Elena, "Viroids: Survivors from the RNA World?" *The Annual Review of Microbiology* 68 (2014): 403.
[47] Gago-Zachert, Serra, Sanjuan, and Elena, "Viroids: Survivors from the RNA World?," 404.
[48] Tracey A. Lincoln and Gerald F. Joyce, "Self-sustained Replication of an RNA Enzyme," *Science* 323, no. 5918 (2009): 1229.

the "organic"? Is such a division necessary or helpful for our understanding of an RNA world? What is it about RNA-like viral strategies that allow us to speculate on the birth of genetics? Perhaps the logic of viral continuity necessitates addressing the concept of form.

4.6 Viral and The Concept of Form

> "Can we go further and say that life, like conscious activity, is invention, is unceasing creation?"—Henri Bergson, *Creative Evolution*

> "What value is there, for molecules, and automatic natural selection, to form complicated organisms in which they could only act according to physico-chemical laws?" —Raymond Ruyer, "There is no Subconscious: Embryogenesis and Memory"

Given how scientific research is silent on how the concept of form may pertain to the origins of genetics, in this section, I attempt to address this gap. If DNA is inert and cannot explain the origins of genetics, what is the relation between the logic of contagion, viral-like strategies, RNA, and form? A refiguring of genetics' relationship to the concept of form—as that which forms or is formative—is necessary before meditating on the field's relation with viral-like strategies. That a static, spatial, and geometric idea of concept of form, a form that arrives externally to permeate or shape matter—in other words, the form of preformationism—needs to be critiqued and remade is widely recognized. The way in which preformationism is undone and form itself is *re*formulated, however, is not uniform. In this section I will juxtapose two (very different) theorists, Susan Oyama and Raymond Ruyer, who both rethink form beyond a preformationist frame.

To start, philosopher of science and developmental systems theorist Susan Oyama has investigated the relation between form and genetics. In *The Ontogeny of Information*, Oyama calls for a concept of form that only comes into *in-formation* through the dynamical system that characterizes an organism. Rather than espousing a pre-existing notion of form separate from

matter, Oyama calls for a rethinking of form that cannot be given in advance in relation to organismic developmental processes. Oyama argues molecular biology ascribes a cognitive-causal function to genes. In this schema, "Wherever the cognitive-causal function is housed, that is, whether in the mind of God or in Drieschian vital energies, or in little computer programs in the cell, as long as it [i.e., form] is seen as preexisting and separate from its material realization, it cannot illuminate life processes."[49] Genes perpetuate the idea of there being an animating "ghost" in a machine that needs activation. For Oyama, the gene cannot be the source of organic form.[50] Form is not waiting in genes or the environment. Instead, "it is constructed by developmental processes." If the gene is the contemporary rendition of form, a static preformationist idea of form, as well its conceptual rebirth as information, it cannot preexist developmental processes. Form neither exists in genes nor in an environment. It instead must be constructed by developmental processes.[51] Information becomes "meaningful" and significant only through its constitution in and by a development system.

> In fact, the habit of thinking about phylogeny and ontogeny as *alternative processes whereby information enters the organism* is the very frame which our endless nature-nurture disputations are woven...Yet information 'in the genes' or 'in the environment' is not biologically relevant until it participates in phenotypic processes. *It becomes meaningful in the organism only as it is constituted by its developmental system.* The result is not *more* information but *significant* information.[52]

This conceptualization of information shifts the emphasis of ontogenesis to the larger dynamic

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[49] Susan Oyama, *The Ontogeny of Information: Developmental Systems and Evolution* (Durham and London: Duke University Press, [1985] 2000), 15.
[50] Oyama, *The Ontogeny of Information*, 13.
[51] "Organismic form, then constant or variable, is not transmitted in genes any more than it is contained in the environment, and it cannot be partitioned by degrees of coding or by amounts of information. It is constructed in developmental processes" (Oyama, *The Ontogeny of Information,* 26).
[52] Oyama, *The Ontogeny of Information*, 16.

developmental system. Meaning is constructed in the formation of an organism itself. Oyama is adamant that form is never given in advance. Rather, it is endless and ongoing and always in-formation: "The developmental system, however, does not have a final form, encoded before its starting point and realized at maturity. It has, if one focuses finely enough, as many forms as time has segments."[53] Thus while form has a directed orientation to the future, Oyama does not address the question of how form travels from a "parent" cell to offspring. While form is not preexisting for Oyama, the orientation of form in *The Ontogeny of Information* does not address the continuity of that straddles the divide between the chemical and the organic. How might form meditate the continuity from the inorganic to the organic, a question that is at the heart of origins of life research?

In the works of French philosopher Raymond Ruyer (1902-1987), we find a completely different notion of form that may address the origins of genetics, and life in a theoretical vein. Unlike Oyama, who does not address the origins of genetics nor cellular life, Ruyer argues that within his metaphysical framework, the problem of the origins of life has already been solved. This is because the question of where and when "life" begins is no longer relevant. As such, a separate vital principle to explain life is no longer necessary here. Ruyer argues that vitalist definitions of life—often construed using the idea that "life is the totality of forces which resist death"—are both "incontestable" and "insufficient."[54] These vitalist definitions are *incontestable* because the thematic activity that marks life, beginning with the development of the embryo and throughout its adult life (in a diminished form), is a process of morphogenesis and regeneration that does indeed *resist* wear, but it does so through the activity of invention. Vitalist definitions

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[53] Oyama, *The Ontogeny of Information*, 27.
[54] Ruyer, *The Genesis of Living Forms*, trans. Jon Roffe and Nicholas B. de Weydenthal (London: Rowman and Littlefield, 2020), 8.

about life being a totality of forces that resist death miss this emphasis on morphogenesis and invention, and therefore are also insufficient. Against this, Ruyer argues that "above all, an organism which constructs itself does not limit itself to [the] resistance [of death] – it creates forms."[55] The creation of form is at the heart of the origins of not only biology but also physics and chemistry for Ruyer. It is precisely this conceptual figuration that contemporary origins research, even when it directs its attention to RNA, does not address.

The operations of form in Oyama and Ruyer are different. While Oyama stresses that form cannot be separated from matter, there is only so much one can do with her theoretical repositioning of form. The way in which Oyama addresses form does not help us address the emergence of life. For Oyama, form is always posterior, it must be constructed through developmental processes. In contrast to Oyama, a reimagining of form for Ruyer necessitates a rethinking of the very structure of space and time. Here, form, specifically primary form, is both anterior to and coincides or subsists with(in) an organism, and is outside of the parameters of both space and time. Form "lives" within a trans-spatial domain and unfolds a mnemonic theme, which is vertically linked to geometrical space and time. Form is not waiting to become an embryo or organism unchanged. There is a continuity, and divergence of forms for Ruyer that stem back to the origins of the universe itself.

Ruyer distinguishes between two kinds of forms—one that we are perhaps familiar with and another that is harder for us to grasp. First, he develops a concept of primary form by reformulating its relation to consciousness. For Ruyer, consciousness does not begin with a brain, but instead is something much more primordial that touches all "primary beings." Primary beings are those that have a certain consistency that allows them to be self-forming or self-making.

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[55] Ruyer, *The Genesis of Living Forms*, 9.

Primary consciousness or form thus cannot be understood from an external perspective. As such, primary beings or primary form involves a reconceptualization of consciousness itself, where consciousness is no longer *consciousness of* something but instead embodies a kind of auto-affection that ceaselessly creates itself—that is its only aim. Primary consciousness only addresses and touches itself. As such, the presence of primary forms can never be observed, but rather only inferred. A molecule, a virus, and a living organisms are all examples of primary forms.

The concept of secondary form is more perhaps familiar and consists of what Ruyer calls "aggregates" or crowd phenomena. These secondary forms are externally brought together and do not have the internal resonance of primary forms. Secondary forms

> exist in material equilibrium. Whether natural or cultural, they are an aggregation of material elements brought together into a composite structure. A house, a car, a bridge. These are all planned structures, aggregates, or composites, subjected to wearing and decay, surviving as long as they do largely due to inertia or external intervention (maintenance, repairs…secondary forms, are capable of mechanical composition and thus either decomposition or recomposition. Secondary forms can be understood external and composed and created mechanistically—that is step by step.[56]

Secondary forms do not actively maintain themselves. This is because they are externally brought together in a step by step manner (like the *in vitro* experiments discussed earlier). A machine in its "traditional" sense that is composed of exterior parts that are joined together is an example. So is a fossil of something that was once alive. While it once had the ability to make itself, a fossil's existence is subject to external physical and chemical forces. Secondary forms can be brought externally brought together, and because of this, they lack the dynamic unity and self-making capabilities of primary form.

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[56] Elizabeth Grosz, *The Incorporeal: Ontology, Ethics, and The Limits of Materialism* (New York: Columbia University Press, 2017), 215.

Ruyer bases his concept of primary beings or forms on quantum physics and chemistry. This revolution moves away from a strict valence-based understand of atoms rooted in a corpuscular theory of matter, in which the smallest elements of matter are point-like particles that make up the "building blocks" of reality. Ruyer argues that "chemical substances as characterised less by a structure than by an ensemble of structural states or *structural behaviors*."[57] In other words, the atom, as a primary form, itself is a structuring activity wholly in touch with and in possession of itself. A carbon atom cannot be understood as a rigid structure composed interior of protons, neutrons, and electrons. The positions of electrons in the carbon atom cannot be precisely pinpointed because the matter that foregrounds reality is not, and therefore cannot be understood as, point-like minute *particles*.[58] They instead involve "electron density maps which represent, depending on the profile of the level, the means of structuring comportment."[59] This atom, which has the capability to form four bonds, "is not a structure but a *structuring activity*."[60] In other words, the atom is not an entity that is constructed together by physically linking together bonds edge-to-edge. The unity and the activity of the structuring behavior that *is* the atom is primary form itself. Ruyer's rethinking and dynamization of form at the subatomic level allows for a very different engagement with biology, including genetics, as well as how we understand RNA and viruses. This brings Ruyer to argue that "verticalism, the dynamic deployment of

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[57] Ruyer, *The Genesis of Living Forms*, 35.
[58] Though I do not have the space to further unpack this claim, thinking matter, especially at the atomic and subatomic level, *beyond* the idea of the particle—in other words, beyond the corpuscular theories of matter we have inherited from Descartes and Newton—is crucial. Philosopher of science Milič Čapek argues that the philosophy of nature (not the philosophy of nature in the sense of romantic *Naturphilosophie*, but philosophy of nature in a wider and more general sense) should begin with the concept of the *event* rather than the particle. See Čapek, "Particles or Events?" in *Physical Sciences and History of Physics*, ed. Robert Sonné Cohen and Mark W. Wartofsky (Dordrecht: Springer, 1983), 1-28.
[59] Ruyer, *The Genesis of Living Forms*, 35.
[60] Ruyer, *The Genesis of Living Forms*, 36.

functional elements is primordial, *in chemistry as in biology*."[61] Verticalism is a metaphor that coincides with formation—it is the appearance of new forms. Function, on the other hand, is perpendicular to formation and coincides with structure, which is why it is not externally observable. Ruyer writes:

> In morphogenetic terms, though, there is a thematic continuity, while in terms of functioning, there is a positional continuity. If it were not so difficult to impose an absolute terminological rigour on this point, the words 'form' and 'structure' could be made more precise by noting that vertical morphogenesis manifests a thematic continuity of forms and that horizontal physiology manifests a permanence of the structure despite changes of position. In the first case, there is a passage from one form to another; in the second, there is a passage from one set of positions to another.[62]

This shift from understanding chemical bonds as rigid-structure of atoms to a structuring activity conceptually reframes bonds as "a systematic unity and not as a sum of elementary actions."[63] This results in the reorientation of the origin of life itself by finally divesting it from a vitalist project:

> So, like the problem of the origin of life, the problem of the origin of the so-called vital—it would be better termed 'microorganic'—force no longer arises. Macroscopic organisms are progressively formed along the lineage of individuality of the universe, through colonization, dominant division, and hierarchical association of microorganisms, that is of molecules. 'Vital force' does not differ in nature from physical force, from the force of internal bonds of atomic physics's [*sic*] unitary domains of action, whose 'force,' as it appears in classical physics, is merely a statistical resultant.[64]

Vital force here ceases to be different in nature than the forces that constitute matter. At the same time, Ruyer suggests that materialism cannot explain primary forms. Instead, in this metaphysical schema, matter itself "has been resolved into domains of action whose essential traits are identical

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[61] Ruyer, *The Genesis of Living Forms*, 36.
[62] Ruyer, *The Genesis of Living Form*, 10.
[63] Ruyer, *Neofinalism*, trans. Alyosha Edlebi (Minneapolis: University of Minnesota Press, 2016), 202.
[64] Ruyer, *Neofinalism*, 202.

to those domains of absolute survey."[65] Absolute survey is synonymous with the structuring activity that *is* matter. Matter in absolute survey is a particular kind of auto-affection in which matter wholly possesses itself, producing a kind of unity that cannot be observed from the outside, but only inferred. It is this activity of matter as primary form that marks the atom and the molecule as much as it does the cell and the developing embryo. The continuation of primary forms in a trans-spatial domain solves the question of how to understand the movement from "inorganic" to the "organic" world. Such a partitioning is no longer necessary within this reformulation. The origin of life extends the fibrous thread of primary form that itself dates back to the origins of the universe.

Returning to the question of the origins of genetics, we find a completely different approach to the relation between organic life and genetics if we think with Ruyer. Solely concentrating on and equating genetics with the genesis of form does not and cannot explain the processes of form-taking activities themselves. On the question of genetics, he notes:

> ...it is just as absurd to explain the structure or evolution of the organism by the chromosomes as it is to explain the harmonium by the play of timbers or the car by the dashboard. The genetic mechanisms do not exempt the biologist from the recourse to finalist factors; they are organs in the service of a finalist direction.[66]

The thematic continuity of primary form resides in a transspatial and transtemporal domain that coincides with the structures one witnesses in geometrical space-time. The ongoing genesis of a thematic continuity of forms, which operate in a transspatial and transtemporal domain that subsists within geometric spacetime, is what generates invention. Without an orientation or a theme, genetics, even at its origin, cannot explain the beginnings of organic life. The origins of

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[65] Ruyer, *Neofinalism*, 208.
[66] Ruyer, *Neofinalism*, 189.

RNA, even-if viral like in its strategy, not only demonstrates a continuity of primary forms, but also is an elaboration of a theme which subsists in geometric spacetime.

In addition to subatomic physics, a field of study that Ruyer bases his metaphysics on, is embryogenesis. An embryo is a primary form because it is solely invested in its self-making. Though it requires an exterior milieu for its home, in its self-formation, the embryo does not direct itself to anything outside itself. There is something embryonic that remains in all primary beings. This includes unicellular entities such as protozoa: "The unicellular entity or the embryo in its initial stage is a completely dark vision and not a non-vision. In other words, it is primary consciousness of its own form and not secondary consciousness of this primary form modulated by sensory contributions that do not yet exist."[67] Primary forms direct their focus solely on self-making to such a degree that the experimental manipulation and moving of parts of an animal embryo in some species does not stop the mnemic theme that is unfolding. Here, Ruyer refers to Hans Driesch and Hans Spemann's well-known embryological experiments. Driesch conducted an interesting experiment using sea urchin embryos in which he cut the sea urchins embryos very early in their development. This splicing did not halt the embryonic development of the sea urchin germ cells but instead resulted in two, fully functioning smaller sea urchins. Spemann is known for conducting an experiment that also demonstrated how life begins with a kind of equipotentiality. Using embryonic animal cells in the early stages of development, Spemann cut and grafted portions of a frog cell from a region that would become a frog brain onto a triton larva in its cellular region that would develop into a mouth. Instead of the frog cells developing into frog brain, they instead developed into a tadpole mouth. Both experiments suggests that there is a particular tune or mnemic theme that operates in early formation that is self-directed yet open

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[67] Ruyer, "There is no Subconcious: Embryogenesis and Memory," 26.

to perturbation precisely because of its self-directedness. The development of the particular cellular part that will form coincides with the mnemic theme or melody that subsists in that particular spatial configuration of the embryo.

Along the same line as Ruyer, but much earlier, Estonian ethologist Jakob von Uexküll argues that these experiments open "the way for a deeper understanding of the technology of Nature."[68] This is because "Everything physical can be cut with a knife—but not a melody."[69] Uexküll's evocation of a melody largely coincides with Ruyer's idea of a mnemic theme. A melody playing itself or a mnemic theme unfolding involves a particular kind of unity that cannot be divided, but can reorganize, and continue to subsist in materiality. Ruyer argues that a mnemic theme that loses its subsistence in spacetime cannot be replayed if it is severed from spacetime.

Ruyer's philosophical project challenges the idea that "visible and tangible matter" form the base of reality and are more "real" than senses, ideas, and values. These are not merely something we imbue the material with after their emergence in spacetime. His proposal of *neo*finalism, the idea that organisms move towards an *end* through a melodic or mnemic theme, is something that the life sciences, including origins research, cannot directly address even though this tendency is the reason life exists in the first place. In a similar vein, von Uexküll argues that the question of life is one of meaning. For von Uexküll, the beginning of life coincides with the emergence of meaning. In particular, he emphasizes how meaning is made in relation to one's environment: "*The question as to meaning must therefore have priority in all living beings*. Only once it is solved does it make any sense to research casually conditioned processes, since the

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[68] Jakob von Uexküll, *A Foray into the Worlds of Animals and Humans: With a Theory of Meaning*, trans. Joseph D. O'Neil (Minneapolis: Minnesota Press, 2010), 194.
[69] Uexküll, *A Foray,* 194.

activity of living cells is directed by their self-tones."[70] There is no schism for Ruyer between the inorganic and organic. "Living" matter is able to be in touch with itself through the physical and chemical properties of matter itself. Uexküll, on the other hand, separates nonliving matter from living matter and does not precisely explain this transition.[71]

A Ruyerian approach to the question of form is metaphysical and thus at odds with origins research focused on the concrete physicochemical generation of particular kinds of genetic entities, in which the philosophical implications of such research are not addressed. But perhaps this is why Ruyer is potentially a necessary antidote for this kind of research solely focused on generating the right kind of nucleic acid precursors *in vitro*, as well as research that marvels at the intricate structures of present day RNA organisms. In his preface to the English translation of Ruyer's magnum opus, *Neofinalism*, Mark Hansen writes that "the ultimate aim of Ruyer's philosophy is precisely to provide the metaphysical basis on which the empirical findings of scientific research can be made to cohere."[72] Thus with Ruyer one can think about why the creation of genetic entities occur, of why there was perhaps a viral-like RNA like tendency moving towards the origins of cellular life.

Ruyer's conception of primary form addresses what Hans Jonas (in the previous chapter) describes as living form. On this, Elizabeth Grosz writes,

> If living things are never stable forms, always undergoing change, nevertheless there is something that subsists in these changes: not anything bodily—for every cell and organ is in the process of self-regeneration or self-replacement—but what Ruyer understands as a

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[70] Uexküll, *Foray*, 151

[71] Though this is understandable given how he is more interested in ethology, and indeed is the first ethologist. In *Theoretical Biology*, Uexküll argues that theories of spontaneous generation, as well as theories that assume "that the very first living things of all must have arisen from a primordial flux," are used to "get rid of conformity with plan as a natural factor" (New York: Harcourt, Brace, and Company, Inc., 1926), x-xi.

[72] Mark B.N. Hansen, "Introduction," in *Neofinalism*, trans. Alyosha Edlebi (Minneapolis: University of Minnesota Press, 2016), viii.

> melodic or mnemic theme, not locatable in space or time but that subsists and accompanies life, and all primary forms, through its processes of autoaffection.[73]

For Ruyer, a mnemic theme operates through its development in space and time.[74] It is this unfolding of a mnemic theme in three-dimensional space that directs formation rather than environmental signals or stimuli themselves. Here potential "is not only mnemic, it is also inventive. The potential-theme is truly creative and the creative aspect of the theme is inseparable from the mnemic and repetitive aspect."[75]

In addition to having already evolved RNA's self-replicate, another core focus of origins research is the chemical-material constitution of the nucleotides in laboratory conditions as well as RNA oligomerization (or the elongation of RNA strands). If one can make RNA "from scratch" (using preactivated compounds) in conditions of the ancient Earth, the question of genetics seems to be solved. But as witnessed with Spiegelman's monster and Joyce's directed evolution of RNA, the generation of particular pre-activated nucleotides or enzymes extracted from preexisting biological organisms or motifs does not address the complexity of the problem at hand. Invention itself becomes impossible here. What instead occurs is the scientific use of the products of morphogenetic invention that are *then* further experimentally honed. Indeed, especially in the case of *in vitro* generation of nucleotides, "the attempt to derive organisms from a secondary arrangement that supervenes over physical masses, conceived as primary, is doomed to failure."[76] This is not to suggest that a primordial RNA did not once exist. But perhaps an RNA world can come into being if it is rooted in some way to primary form, because this would be a

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[73] Grosz, *The Incorporeal*, 216.
[74] Hansen, "Introduction," xix.
[75] Ruyer, "There is no Subconscious: Embryogenesis and Memory," 32.
[76] Ruyer, *The Genesis of Living Form*, 41.

continuity of the activities of atoms and molecules, beings that are not yet considered biological.[77] It is here that RNA possibly evolving through "viral-like" strategies comes into play.

If there is a viral-like beginning to genetics, and the creation of forms is intertwined with primary beings, the development of morphogenesis hinges on a trans-temporal and trans-spatial unity. This peculiar entity that "bridges" inorganic and organic life in the contemporary scene, for Ruyer, is part of the fibrous thread of continuity that all primary beings share, through a kind of descent with modification, with the beginnings of the universe itself:

> This triumph of "materialism" is illusory. To affirm that microorganisms are molecules is to admit, in the same stroke, that molecules are microorganisms. The universe's "fibrous structure," made up of individual lines of continuity, is the capital fact underscored by all the recent discoveries. The physics of "individuals" enters into continuity with the biology of individuals. The living organism can no longer be reduced to a complex of physicochemical phenomena in the ordinary sense of the term, that is, into aggregate and statistical phenomena. Physicochemical phenomena certainly unfold in the organism and are used by it; but they are not the organism itself.[78]

This is not to say that all primary forms are the same. The continuity of primary forms that develop through the transspatial and transtemporal domain that actualize into spacetime continue to unfold along divergent lines, but they share a continuity *from* a common origin.

Here, the distinction between "inorganic" and "organic" life loses its stability given how morphogenesis is a continuity of primary organisms unfolding a melodic theme. This is perhaps why viruses occupy a particular position in Ruyer's reformulation of the origins of life. Here, the focus is not on whether viruses are alive. Instead, viruses embody a link, or transition between molecules and unicellular organisms. The virus itself, when in a materially homed space that can

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[77] It would also automatically link RNA, as primary form, to the operations of atoms and molecules that are not yet considered biological. This is the focus of the next chapter.
[78] Ruyer, *Neofinalism*, 154.

be pre-cellular or cellular, unfolds a theme that results in the invention of new forms. On this, Ruyer writes:

> Even though from the heart of the molecule to the macromolecule and the virus and then to the unicellular organism everything is subordinated to crowd phenomena, however large they become, they remain in this sense 'microscopic.'[79]

Viruses trouble the possibility of thinking there is a set beginning to life. They instead suggest a continuity between chemical bonds and cellular beings by existing in the spaces between these two sets of primary beings. Viruses share a continuity with the development of primary form that leads to unicellular organisms. This connects to how Koonin and Martin suggest that within iron-sulfide compartments, "populations of virus-like RNA molecules, when even eventually encoded one or a few proteins each, became the agents of both variation and selection."[80] This initial phase of genesis would make viral-like actors indistinguishable from the "would-be prokaryotic genomes" to come.[81] While continuity is emphasized in both of these accounts, it addresses different things. Most origins research suggests a continuity thesis between matter and life, they do so through a focus on the "suitable physical conditions" that cellular life would require.[82] Koonin and Martin suggest that within this sphere of viral-like entities, natural selection placed evolutionary pressure on self-replication.

How does a viral perspective change how we understand the origins of genetics through RNA? Scientific research that acknowledges viruses as entities that do more than just harm their

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[79] Ruyer, *The Genesis of Living Form*, 32.
[80] Eugene V. Koonin and William Martin, "On the Origins of genomes and cells within inorganic compartments," *TRENDS in Genetics Vol.21 No.12 December* (2005): 647.
[81] Koonin and Martin, "On the Origins of genomes and cells," 650.
[82] Iris Fry, "Are the Different Hypotheses on The Emergence of Life as Different as They Seem?" *Biology and Philosophy* 1995 (10): 387.

hosts have shifted their language toward these liminal beings. One text focusing on viruses notes how they are agents that are genetic engineers:

> The change from a mechanistic view of molecular biology on nucleic acid sequences as random assemblies of physical entities to an agent-based perspective on genetic texts as the result of complex viral-driven natural genetic engineering seems to be on the horizon. Investigations can now focus on action and interaction motifs of persistent viral consortia with their hosts rather than solely on physical and chemical properties. Agent-driven natural genome editing of genetic text sequences is completely absent in inanimate nature. Therefore, the borderline between life and non-life is not only metabolism but the emergence of natural genome editing.[83]

Viruses embody the shift from the beginnings of nucleic acids comprising random incidents to agent-based change. If viruses and viral-like entities truly invented RNA, it is because they are the unfolding of primary forms themselves. The evocation of "virus" is often the closest origins research comes to articulating a theory of the emergence of genetics where the explanation outside of pure natural selection exists. Perhaps viral-like strategies of RNA mark the lines of continuity of all primary beings in the universe. If there was once an RNA, it would need to consist of more than just the physicochemical production of nucleic acids. Genetics itself cannot embody life. Genes and genetics are instead like "organs in the service of a finalist direction."[84]

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[83] Günther Witzany, "From Molecular Entities to Competent Agents: Viral Infection-Derived Consortia Act as Natural Genetic Engineers," in *Viruses: Essential Agents of Life* (New York: Springer), 407-419.
[84] Ruyer, *Neofinalism*, 189.

5. Memory and Morphogenesis: From the Chemical to the Organic

"Memory is not the property of bodies. Bodies, or what appear as 'bodies,' are the property of memory."
—Raymond Ruyer, "The Status of the Future and the Invisible World"

Life carries within it something of its past into its present. It inherits some form of heredity from its past that it further develops and complexifies in its present in order to generate a future that cannot be predicted or given in advance. According to nineteenth-century German evolutionary biologist August Weismann, the problem of heredity must entail "the existence of a special organized and living *hereditary substance*, which in all multicellular organisms, unlike the substance composing the perishable body of the individual, is transmitted from generation to generation."[1] For Weismann, this hereditary substance was "immortal" in a sense and resided in germ-plasm (found in egg and sperm cells), which he distinguished from "mortal" somatoplasm (soma or body cells).[2] The development of genetics in the twentieth-century, with the deciphering of the structure of DNA as well as the nature of chromosomes, in a way confirms Weismann's concept of germ-plasm with increasing detail. It is easy for us to understand heredity in relation to a physical entity such as a germ-plasm or gene in and across life that has already formed, but how might we understand the origins of heredity before there is a definite hereditary substance of some sort? What are the conditions of heredity itself that make a heredity substance possible? And furthermore, does a *substance* of sorts—whether germ or gene—mark the beginning of heredity, or is substance itself an effect of some larger process?

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[1] August Weismann, *The Germ-Plasm: A Theory of Heredity,* trans. W. Newton Parker (New York: Charles Scribner's Sons: [1892] 1898), xi.
[2] This substance is "immortal" for Weismann only to the extent that there is reproduction.

In this chapter, I engage with the concepts of heredity in a way that accounts for genetics but deals with heredity and memory in a much broader ontological sense. Although Weismann does not use the term, I am interested in a theory of *memory* that conditions and subsists within cellular life. This theory of memory and heredity may encompass and explain the emergence of genetics, but it would also necessarily extend further back in time before the advent of genes. In other words, one of the central premises of this chapter is that neither memory nor heredity begin with genetics. To argue that memory can be wholly explained by "genetics," which always tends towards reductionism, would generate a theory of origins that is binaristic. Such a theory would be binaristic because it would (attempt to) pinpoint exactly when memory "enters," and therefore would erect an insurmountable gap between matter and life. My aim in this chapter is to think how a philosophy of memory is part and parcel of a philosophy of life in a way that does not create a dualism between "nonliving" and "living" or "inorganic" and "organic," and to offer a more philosophical engagement with memory, specifically by calling on a lineage of philosophy that challenges the idea of memory as substance.

In his 1907 text *Creative Evolution*, Bergson argues that living systems are guided by organic memory, in which the whole of the past is concentrated in their living present. The whole of past endures within a living system and it this complete immersion in the past that constitutes organic memory:

> The evolution of the living being, like that of the embryo, implies a continual recording of duration, a persistence of the past in the present, and so an appearance, at least, of organic memory.
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> The present state of an unorganized body depends exclusively on what happened at the previous instant; and likewise the position of the material points of a system defined and isolated by science is determined by the position of these same points at the moment immediately before...Is it so with the laws of life? Does the state of a living body find its complete explanation in the state immediately before? Yes, if it is agreed a priori to liken the living body to other bodies, and to identify it, for the sake of the argument, with the artificial systems on which the chemist, physicist and astronomer operate. But in

> astronomy, physics and chemistry the proposition has a perfectly definite meaning: it signifies that certain aspects of the present, important for science, are calculable as functions of the immediate past. Nothing of the sort in the domain of life. Here calculation touches, at most, certain phenomena of organic *destruction*. Organic *creation*, on the contrary, the evolutionary phenomena which properly constitute life, we cannot in any way subject to a mathematical treatment. It will be said that this impotence is due only to our ignorance. But it may equally well express the fact that the present moment of a living body does not find its explanation in the moment immediately before, that *all* the past of the organism must be added to that moment, its heredity in fact, the whole of a very long history.[3]

Bergson distinguishes between the concrete time of living systems and the abstract time of artificially closed systems of scientific experiments. Living systems are systems that Nature itself has closed off while artificial systems are closed off by Man. Artificial systems, what Bergson also refers to as unorganized matter, abide by *abstract* time, in which time conceptually and mathematically figures as an independent variable *extrinsic* to a system. The present state of an artificial system finds its "complete explanation in the state before."[4] In contrast, living systems (or organized matter) live in *concrete* time. Here the present state of a living system cannot be understood from the state that immediately comes before. Instead, "[i]ts past, in its entirety, is prolonged into its present, and abides there, actual and acting."[5]

The physics and chemistry of the late nineteenth and early twentieth-century that coincide with the time during which Bergson wrote *Creative Evolution* utilized abstract time. They therefore were unable to account for concrete time, the specific kind of time in which organic memory unfolds. Writing a generation after Bergson in the wake of major advances in physics that revolutionized how we understand the reality of Nature, Raymond Ruyer is able to take up

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[3] Bergson, *Creative Evolution*, 23-4.
[4] Bergson, *Creative Evolution*, 25.
[5] Bergson, *Creative Evolution*, 19.

the question of the relation between organic memory and life in novel and innovative ways.[6] The binary between the living systems demarcated by Nature and the artificial systems of science becomes undone by the time Ruyer is writing in the mid-twentieth century. More specifically, physics and chemistry cease to only address artificial systems and a continuity between the physical and chemical *that could* engender organic memory becomes possible. The theoretical relation between *memory* and life is a central question for biology (even if it is not explicitly voiced as such) and therefore must be attended to within a philosophy of life that addresses the continuity of the real. Ruyer does exactly this. Thinking with Ruyer about life and memory in relation to morphogenesis provides a rich resource to theorize the relation between chemical morphogenesis and organic morphogenesis in a way that does not parse physics and chemistry from biology.

In *Neofinalism*, Ruyer argues that the problem of the origins of life can no longer be seen as an enigma we will never solve. For Ruyer, this means that

> [i]n a certain superficial sense, we can say that contemporary science has realized the hopes of the old materialism concerning the problem of life. We can say that the problem of the historical origin of life no longer arises. The appearance of life from a geologically "dead" world can no longer be considered as one of the forever-insoluble "enigmas of the

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[6] Ruyer is mostly critical of Bergson in the few places in *Neofinalism* and *The Genesis of Living Forms* he addresses him. In his 1959 essay called "Bergson and the Ammophila Sphex" (*Bergson et le Sphex ammophile*)"—a piece in which he mainly defends Bergson's concept of instinct against prominent critiques of his day—Ruyer diagnoses Bergson's problematic binarization between physics and chemistry on the one hand and life on the other as a symptom of him being born at the wrong time. Ruyer writes: "Bergson's real philosophical misfortune is to have been born at a very bad time. At the end of the nineteenth century, one had doubts about the artificial character of mechanistic and deterministic science but one saw no other solution than to seek the truth outside of science. One could not anticipate the scientific revolution that micro-physics was about to bring by discovering the domains of individuality beneath the secondary and statistical laws. Micro-physics also permits one to follow the progressive com- plication of lineages of individualities, from the atom to macro-molecules, to viruses, to cells, to multicellular organisms on the one hand, and the appearance of classical secondary laws when multitudes of individuals are considered in their assembly [ensemble] and in their statistical effects on the other" (Ruyer, "Bergson and the Ammophila Sphex," *Angelaki* (2019) 24, no. 5: 134.

> Universe." The modes of emergence of complex organisms are far from being known, but the emergence of life, considered as an absolutely novel mode of being, is no longer a philosophical problem. There is no longer any reason to believe that from a chemical molecule to a bacillus, the abyss is greater than from a bacillus to a vertebrate. Physicochemical sciences and the sciences of the organism are much closer to each other than they were in the eighteenth and nineteenth centuries. They have already blended together in practice. The study of crystallizable viruses, genetic mutations, and large organic molecules in general attracts both chemists and biologists.[7]

The origins of life ceases to be enigmatic because the gap "between" physics and chemistry on the one hand and biology on the other no longer exists. This chapter thinks in the space that unfolds from the physicochemical and the organic to consider how viruses offer us the grounds to theorize how memory, reproduction, and instinct begin in the organic realm.

In the previous chapter, I focused on research that speculated on the beginning of genetics in a hypothetical RNA world, and argued that the origin of genetics is deeply linked to the ontological question of form in a Ruyerian sense of the term. The genesis of living form poses a difficult question for gene-centric origins research in non-preformationist terms, which is a particularly problematic issue because proto-genesis has everything to do with form. While modern-day genetic explanations often conventionally understand that DNA in cellular forms acts as a kind of blueprint, how do we make sense of a scenario of life's origins where there is no initial informational storage to draw from or use to construct an organism? In relation to this, I spotlighted research that suggests that the beginning of RNA was viral in nature. My goal in exploring the possible viral origins of genetics (in a putative RNA World) was to consider the ontological consequences of this speculative hypothesis regarding the beginnings of cellular life. Here I continue this line of thought by focusing on how Ruyer's conception of viruses as primary forms provides us with a philosophical model to understand the relationship between chemistry,

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[7] Ruyer, *Neofinalism*, 154.

biology, and memory that does not depend upon, and indeed makes possible, some kind of hereditary *substance*.

In addition to focusing on research that directly considers the role viruses may have played in the beginnings of genetics, in this chapter, I consider scientific experiments that highlight the strange capacities of viruses that can be gleaned from contemporary research. Viruses 1) comprise a significant portion of existing genomes, 2) can be crystallized by researchers, 3) can spontaneously re-assemble after they are chemically denatured or disassembled, and 4) can be generated by researchers *de novo* or "from scratch" by downloading their genetic code from online databases. I pay particular attention to research that manipulates viruses by disassembling them, only to have the disintegrated viruses re-assemble themselves. These experimental manipulations of viruses are an invitation to delve deeper into understanding their status, to use Ruyer's term, as primary forms. I will argue that these experiments are akin to the famous "vitalist" embryological experiments of the early twentieth-century, such that of Hans Driesch and Hans Spemann, well known among humanities scholars interested in the nonhuman.[8] These experiments signify the internal resonance of matter that can be observed when it is in its embryological unfoldings, when it is most in touch with itself and full of equipotentiality as a primary form. These strange experimental demonstrations—though they focus and manipulate *present-day* viruses (which range from ones that infect bacteria to viruses that cause polio) rather than viruses at the origins of genetics billions of years (which are impossible to access)—nonetheless provide the raw materials to understand what a feminist philosophy of life would entail.

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[8] Jane Bennett can be credited as popularizing these experiments in *Vibrant Matter: A Political Ecology of Things* (Durham and London: Duke University Press, 2010).

5.1 Viruses and Evolution: Insights from Contemporary Science

Viruses have invented (and here I am using these words deliberately in relation to a nonhuman agent) a vast array of genetic systems more so than any other cellular life forms. The latter exclusively use double-stranded DNA as their form of informational molecular storage. In contrast to this singular form of storage, viruses use four: viral genomes can be single or double stranded RNA as well as single or double stranded DNA. This wide variety of nucleic hereditary possibilities suggests that viruses have an intimate connection with, and creative capacity to invent, genetic systems and novel genes. Moreover, when we assess the contemporary genetic makeup of life forms such as human beings, we find that specific kinds viruses called retroviruses are integrated within and account for a sizable portion of our genome.

That viruses have been key agents in the evolution of life cannot be disputed. This has especially become evident with the discovery that mammalian evolution, including human evolution, has been profoundly shaped by viruses. One particular example that underscores this point occurred in 2000, when a study published in *Nature* demonstrated that the evolution of mammalian live birth (as opposed to egg laying birth) was made possible by a protein derived from a gene that was originally *viral* in nature. Live birth is made possible by the mammalian placenta, which is a temporary organ that facilitates the exchange of nutrients and waste between a fetus and the maternal body it gestates within.[9] The 2000 *Nature* study argued that syncytins, a class of proteins in mammals that allow for bodily fluid exchange between fetus and its maternal body, were genomically derived from retroviruses.[10] These types of viruses translate their RNA

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[9] I use "maternal body" in a wider sense than simply the reproductive bodies of cis-women. I define maternal body in a non-anthropomorphic sense as a body that provides the conditions of gestation necessary for birth.

[10] Sha Mi, Xinhua Lee, Xiang-ping Li, Geertruida M. Veldman, Heather Finnerty, Lisa Racie, Edward LaVallie, Xiang-Yang Tang, Philippe Edouard, Steve Howes, James C. Keith Jr and John

genomes into DNA and fuse with host DNA. Viruses, or viral genes to be more exact, enabled the evolutionary shift from an external embryogenesis (egg-laying and maturation outside a body) to internal embryogenesis rooted in gestation. Syncytin allows the embryo to implant in the womb. Syncytin is the mammalian name of the protein; in viruses these kinds of proteins are formed from *env* viral genes (which enable viruses to fuse to the membrane of their host cells). The presence of endogenous retroviruses within mammals has enabled mammalian species to *exapt* (i.e., adopt for their own purpose) what were originally viral genes (necessary to merge with cellular membranes), and in the process, fundamentally transform the process of birth.

Many of the viral remnants in human genomes are no longer active due to undergoing many mutations over time, becoming molecular fossils in our DNA. Calls for understanding viruses as novel genetic engineers (a point I discussed at the end of the previous chapter) have been increasing those attuned to the reality of the effects of viral evolution. One article summarizes this point: "Viruses and related elements introduced genetic information and have shaped the genomes and immune systems of all cellular life forms."[11] Viruses invent genetic novelty and thereby drive the evolution of species. *The idea that viruses may have had a central role in the emergence of cellular life is increasingly being accepted, something that is largely aided by the growing research that demonstrates the symbiotic, inventive effect viruses have had across diverse evolutionary lineages*. This is an active area of research that continues to generate novel insights, such as the viral origins of mammalian gestation discussed above. Acknowledging that viruses and viral-like entities are the creators of novel genes, and therefore

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M. McCoy, "Syncytin is a captive retroviral envelope protein involved in human placental morphogenesis," *Nature* 403 (2000): 785-9.

[11] Felix Broecker and Kain Moelling, "What viruses tell us about evolution and immunity: Beyond Darwin?" *Annals of the New York Academy of Sciences* 1447 (2019): 53.

new traits, is a moment in origins research where morphogenesis as an activity of invention can be discussed. So long as we are talking about genetics, we can discuss invention. While it is important to acknowledge viral inventiveness and that we are in many ways viral effects, my aim in this chapter is to not to focus on these viral evolutionary effects but rather to explore the particular ontological nature of viruses as (what Ruyer would call) primary forms. In other words, while still acknowledging the (often evolutionary eventful) consequences of viral inventiveness, here I explore the ontological nature of viruses that allows such inventiveness to occur.

The question that interests me here is not whether viruses are alive.[12] Not only has the value in debating this problem largely been exhausted within virology and origins research, it also preemptively forecloses the possibility to engage with the ontological nature of viruses. The primary reasons viruses are considered nonliving are that they do not have any kind of metabolism and because they use cellular machinery to self-replicate. The definition of "life" employed here highlights what viruses lack (a metabolism and "true" unassisted "self"-replication). Focusing on why viruses are or are not alive sidesteps the more interesting question of how their liminal status can help reframe how we understand the genesis of living forms and the emergence of heredity and organic memory. I am interested in the inventive qualities of viruses, and how such qualities derive from their status as primary forms that enjoy a particular kind of liminality, a Ruyerian designation that is much more generative to think with than debates about whether viruses are "fully alive."[13]

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[12] For an argument on why viruses are not "alive," see David Moreira & Purificación López-García, "Ten reasons to exclude viruses from the tree of life," *Nature Reviews Microbiology* 7 (2009): R306–R311. For a perspective that firmly disagrees with such an argument, see Luis P. Villarreal and Guenther Witzany, "Viruses are essential agents within the roots and stem of the tree of life," *Journal of Theoretical Biology* 262 (2010): 698–710.

[13] On the other hand, one could also argue that by conceptually expanding the category of life to encompass viruses actually further complicates the conditions from which life arises. Put

That viruses are major agents in evolution cannot be disputed. Though a Ruyerian perspective would affirm this viral capacity to invent—an activity characteristic of a primary forms—it would deploy embryogenesis rather than evolution to understand this phenomenon. Ruyer develops "the process of embryogenesis into a philosophical model for the operation of form as such" over and above evolution.[14] As such, embryogenesis "must take primacy" over both evolutionary theory and genetics.[15] This is because embryogenesis clearly demonstrates the operations of an absolute surface, where the ability for one to reproduce *oneself* (something a machine is incapable of doing) becomes possible and where we most directly witness thematic behavior in its most robust form. Ruyer's assertion that embryogenesis must take primacy over evolutionary theory is, in a way, a direct response to Darwin. In *On the Origins of Species,* Darwin considers whether "descent with modification" can account for embryogenesis, ultimately arguing that it can. Darwin writes:

> How, then, can we explain these several facts in embryology, namely the very general, but not universal difference in structure between the embryo and the adult; of parts in the same individual embryo, which ultimately become very unlike and serve for diverse

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differently, viruses can be inventive and creative and not be alive because it is not only life that is privy to these kinds of activities. On this Ruyer argues that "[t]he price to be paid, if it is one, is clearly that of admitting that every molecule and even every atom is as 'alive' as a virus. An observer of this evolution inattentive to contemporary science might believe they find here a return to vague and out-dated conceptions of animism, to the imaginary attribution of a consciousness to physical matter – a miniaturised human consciousness in the form of a small demon or homunculus, the bearer of freedom, memory and intention. We think that the fear of 'verbalising' must not lead us to fear words. We must not be afraid, that is, of using the words 'organism' and even 'consciousness' apropos of molecules for it is no longer here a question of a careless use of words but, on the contrary, of an interpretation made possible by chemistry and modern microbiology concerning the reality that these words designate...Wherever there is non-functional, formative activity, there is inevitably a 'for itself', self-possession, self-given form bound to itself absolutely and not constituted by secondary step-by-step bonds. Wherever a being comports itself – that is, does more than function within the limits of a given structure – there is necessarily consciousness, that is, the improvisation of bonds according to a theme which is not given in space" (Ruyer, *The Genesis of Living Forms*, 38-9).

[14] Hansen, "Introduction," ix.

[15] Ruyer, *The Genesis of Living Forms*, 25.

> purposes, being at this early period of growth alike; of embryos of different species within the same class, generally, but not universally, resembling each other; of the structure of the embryo not being closely related to its conditions of existence, except when the embryo becomes at any period of life active and has to provide for itself; of the embryo apparently having sometimes a higher organization than the mature animal, into which it is developed. I believe that all these facts can be explained, as follows, on the view of descent with modification.[16]

Ruyer does not deny that evolution (or "descent with modification") occurs. He takes issue with that idea that it can explain embryogenesis. Formative activity provides the basis of evolution; it is evolution's condition of possibility. This is the reason why Ruyer rejects the infamous biological dictum that "ontogeny recapitulates phylogeny." Ontogeny is the development of an individual and connected to embryogenesis while phylogeny is the evolutionary history of a species. Originally developed by German biologist Ernst Haeckel in the late nineteenth century, this is the idea that during the development of an embryo, one can "spatially" witness the entire history of its species past. For Ruyer, ontogenesis is never a passive process that simply repeats phylogenesis. On the contrary, it is ontogeny that prefigures phylogenesis. This is why for Ruyer "'ontogeny does not recapitulate Phylogeny: it creates it.'"[17]

I want to return to the discussion of viruses and the origins of cellular life, but in a tangential way by continuing to explore the relationship between viruses and form, specifically Ruyer's concept of primary form. To recap, primary forms are dynamic structures

> that can never be produced by the accumulation of parts or mechanically, but must always produce themselves before anything can be produced with or from them. Such forms are no longer composites, with parts existing side by side, but a unity or cohesion of forces, a form, that is a structuring activity, one which can be understood but not decomposed. Dynamic forms are self-structuring, that is, they maintain and "repair" themselves, they maintain a consistency and an orientation in the processes by which they continually create themselves.…Primary forms are composed of relations that can be

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[16] Charles Darwin, *The Origins of Species* (New York: Signet, 1958), 369.
[17] Ruyer, *The Genesis of Living*, 25, citing Joseph Needham, *Order and Life* (Cambridge: Cambridge University Press, 2015 [1936]), 157.

> inferred but not observed, or at least are not capable of being observed from an external position.[18]

Primary beings are thematic activities that are self-making, and thus coincide with any and all morphogenetic activity because they are themselves these activities. In other words, primary forms are synonymous with the structuring activities that mark the morphogenetic activity of the atom, as well as the molecule, the virus, the cell, and the embryo. This particular kind of auto-affection allows primary forms to create themselves through thematic activity. For Ruyer, "Nature manifests something that at first appears impossible: as if through imperceptible turns, it engenders organic forms from molecular ones."[19] He dissolves a difference in kind between molecular forms and organic form by arguing that *if* there is a "vital principle," it encompasses both molecular and organism forms. The formative activity of organic forms (such as cells) is a direct continuity, as well as a further elaboration, of molecular morphogenesis. If the emergence of organic life entails memory (or some form heredity) at work, how might Ruyer help us understand viruses' relation to memory and reproduction? This chapter asks how thematic development of primary form moves from the molecular to the organic, and it does so by focusing on how viruses have theoretically and scientifically understood to be key agents in this shift.

5.2 Continuity and Thematism

In the chapter "From the Molecule to The Organism" in *The Genesis of Living Forms*, Ruyer asks how physics and chemistry lead to organic life. To him, it is clear that origin theories

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[18] Grosz, *The Incorporeal*, 215.
[19] Ruyer, *The Genesis of Living Forms,* trans. Jon Roffe and Nicholas B. de Weydenthal (London: Rowman and Littlefield, 2020), 30.

that bring "matter" to life from an external force cannot answer this question. Instead, he asks what qualities in certain physical and chemical structuring behaviors condition the possibility for life to occur. More specifically, if morphogenesis is the unfolding of thematic behavior in space, Ruyer asks: "How can an individualising formative theme come into being or come to be inserted into a[n] edifice constituted, it would seem, by bonds that are linked edge to edge?"[20] The bonds of chemical molecules, when framed as particular pieces stacked side by side, cannot bring about the thematic behavior that would further transform into the organic. This is because such a conceptual schema understands molecules to be composed of chemical bonds that are "hooks" between static objects. Molecules, here, have no internal unity or activity that binds them together because they are externally brought or "glued" together. Inventive, thematic activity with this formulation of chemical molecules becomes impossible. Chemical morphogenesis conditions, and is further complicated by, the activity of organic morphogenesis. Below I delve into how viruses can potentially answer the question of how physics and chemistry can lead to organic life.

Continuing this conceptual thread, given that individual organic development has a thematic character, Ruyer asks how this pertains to origins. In the case of a living cell, "[w]here does this formative theme come from, and at which moment does it intervene in processes of physical functioning?"[21] While the development of an egg or a specific living cell is a complex process that is not (yet?) fully understood, it is less mysterious for Ruyer than the origins of cellular life because it does not involve "the passage of one mode of being to another" that the former entails.[22] Put differently, Ruyer is interested in the origins of organic morphogenesis, where primary forms that are physical and chemical become organic. If embryogenesis is the

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[20] Ruyer, *The Genesis of Living Forms,* 29-30.
[21] Ruyer, *The Genesis of Living Forms,* 29.
[22] Ruyer, *The Genesis of Living Forms,* 29.

unfolding of a theme in spacetime, and though an egg has an intricate organic architecture, this complexity does not "prefigure the future organism" in a preformationist sense. Form is never spatially pregiven (which is the hallmark of preformationist theories).

The passage from an inorganic to an organic mode of development entails that this thematic character continues the activity already found in some kind of chemical molecule, one that Ruyer speculates may be viral in nature:

> The morphogenesis of a species as a whole certainly does not originate with a completely constituted cell but rather something which must have resembled what we today call a virus, a self-reproducing macromolecule. From viruses to higher animals, thematic development seems to come into being at the level of the chemical molecule.[23]

The virus, or chemical molecules like viruses must then have a relationship to thematic activity. If this is the case, they may be understood as absolute forms that have a relation to memory because one can witness a kind of replication at work.

5.3 Viruses as Chemicals

If viruses can be theorized as agents invested in thematic activity, they can also, almost paradoxically, be understood as chemicals in a quite literal sense. In 1935, Tobacco mosaic virus (TMV), a virus that infects tobacco and related plants resulting in a characteristic mottled or "mosaic" appearance on plant leaves, became the first virus to be *crystallized*.[24] This was accomplished in the laboratory using large amounts of TMV infected plant leaves. TMV's ability

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[23] Ruyer, *The Genesis of Living Forms,* 29.

[24] Tobacco mosaic virus holds a crucial place in the history of virology. Discovered in the late nineteenth century, TMV was the first pathogen to specifically be called a *virus* (as opposed to an infectious cellular pathogen such as bacteria). Unlike cellular pathogens, which could be filtered out of mediums using filters, TMV was a pathogen that could not be "caught" by filters due to its extremely small size, and thus retained its capacity to infect in laboratory experiments. Since then TMV has become a model organism in virology and genetics more broadly. I will return to scientific experiments using TMV later in this chapter.

to be crystallized led to the understanding of viruses as giant *molecules* that existed at the boundary of life, making them key objects of study in molecular biology. Because the crystallization of cellular life is impossible, that viruses could be crystallized signaled the radical difference between these two modes of life. Wendell Stanley, the biochemist and virologist who accomplished the crystallization of TMV, was awarded the Nobel Prize in Chemistry in 1946. In his Nobel Lecture, Stanley comments on the unique nature of viruses:

> The fact that, with respect to size, the viruses overlapped with the organisms of the biologist at one extreme and with the molecules of the chemist at the other extreme only served to heighten the mystery regarding the nature of viruses. Then too, it became obvious that a sharp line dividing living from nonliving things could not be drawn and this fact served to add fuel for discussion of the age-old question of "What is life?"

Around the mid-twentieth century, viruses were understood as chemicals due to their crystallizable ability. Ruyer uses this significant biological feature of viruses as an opportunity to further refine his analysis of how chemical morphogenesis may lead to organic morphogenesis. He writes:

> Of course, not everything in the individualised domains of chemistry or at the level of the organism is primary bond. It is clear that the articulation of the knee or the shoulder is no more mysterious than the articulations of a machine. The same holds in chemistry: *given* carbon-hydrogen and carbon-carbon bonds, the passage from methane to ethane, and from butane or aspartic acid to glutamic acid through the H-C-H relay is as clear and straightforward as the construction of a tower of dominoes. The process by which nucleoprotein chains are constructed is on the way to being just as well understood. However complex their subunities might be, crystallisable viruses appear to be composed of regular groupings of these piled-up sub-unities; the crystal of the virus is made in turn of these piles, according to the ordinary laws of the physics of crystals. A mass of these crystals is a long way from primary bonding and consequently from the primary mystery of the virus's individuality.[25]

That viruses can be crystallized (when aggregated in large quantities) demonstrates that they are *chemical* in nature at least in one sense of the term. This ability to be crystallized, however, does

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[25] Ruyer, *The Genesis of Living Forms,* 40, emphasis in original.

not speak to the chemical morphogenetic properties that viruses have within a proto-cellular or bona fide cellular milieu. The thematic development of viruses cannot be approached through their crystallizable capacity. This would instead require a different modality of "chemical" at work in order to account for how chemical morphogenesis becomes organic morphogenesis. From this perspective, the "chemical" nature of viruses must be more than something that is an aggregate of parts that "seemingly function in a step-by-step fashion" such that its "pieces can be added, subtracted or replaced by others."[26] Put differently, what is needed for organic morphogenesis from chemical morphogenesis to arise is a particular kind of macromolecule that shares, and thus preconditions, the kind of morphogenesis one witnesses in a developing organism. The crystallizable nature of viruses does signify their relation at the edge between the inorganic and organic mode, but does not directly signal how they might be primary forms.

A 1955 experiment at the Virus Laboratory at The University of California, Berkeley raises interesting questions of viruses as primary forms that are in a sense "embryonic." This study used tobacco mosaic virus (TMV), the virus discussed above that was the first virus to be crystallized. TMV has a relatively simple architecture: it is a single-stranded RNA molecule encased in a rod-shaped protein envelope. The protein envelope accounts for 94% of the entire virus particle, with the RNA nucleic acid being the remaining 6%.[27]

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[26] Ruyer, *The Genesis of Living Forms*, 29.
[27] Heinz Fraenkel-Conrat, "Rebuilding a Virus," *Scientific American* 194, no. 6 (June 1956): 42.

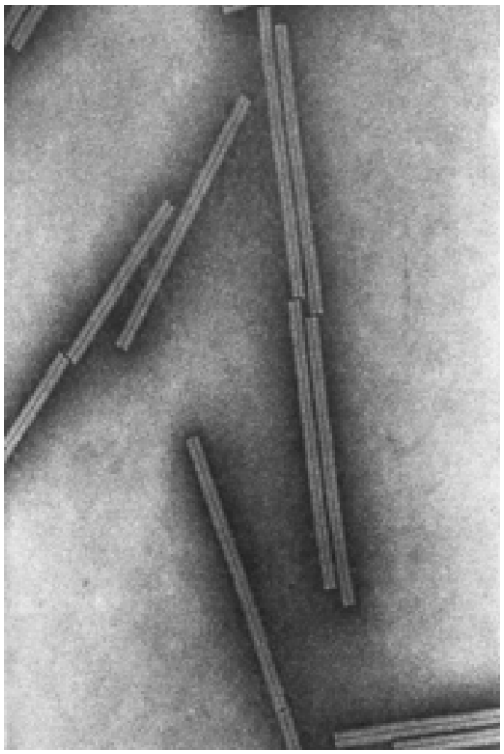

Figure 14: "Electron Micrograph of Rod-Shaped Particles of TMV magnified 300,000 diameter" (Butler and Klug, 1978)

In the 1955 experiment, the RNA nucleic acid component of TMV was dissociated from its protein coat using gentle chemical detergents. Researchers found that TMV was able to reconstitute itself even when disassembled, so much so that viral regeneration could occur through the interchanging of parts of different viral strains of TMV. The thematic behavior of viruses allows for the manipulation and interchanging of viral parts to not deter its self-assembly to become a viable viral particle. What is perhaps most significant in the case of the reassembled tobacco mosaic virus is that it retains, albeit in a much weaker form, its ability to infect. To put this into context, if one were to disassemble a mature adult living cell, and sought to reassemble it after disintegrating into its component parts, its self-organizational capacity would be impossible to regain. According to two researchers, "therefore all the information necessary for constructing

the virus is inherent in its parts, which 'self-assemble' spontaneously in solution."[28] That Tobacco-mosaic virus self-organizes into a virus particle after being cut up into different parts—sometimes with different parts from other viruses—signals something critical about viruses and the question of form. It signifies the presence of a kind of absolute surface at work on which self-assembly occurs. The thematic behavior of the virus allows for the manipulation and interchanging of viral parts which can reassemble even after what seems like a completely destructive act.

Experimental disaggregation of TMV into its protein exterior and nucleic acid interior also allows researchers to experiment with how heredity is passed down from parent to progeny. If one were to disassemble two separate strains of TMV (shown in the figure below) by breaking up its exterior protein coat while keepings its single-strand of RNA intact, and then subsequently reassemble a hybrid TMV that had nucleic acid surrounded by a protein coat from a different TMV strain (represented by the "red" and "black" colors in the figure), the replication of the constructed hybrid produced progeny that fully resembled the TMV particle of the nucleic acid of its parent. This demonstrated to researchers that RNA can be a hereditary material like DNA, something that was not known prior to this 1955 experiment.

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[28] P. Jonathan, G. Butler, and Aaron Klug, "The Assembly of a Virus," *Scientific American* 239, no. 5 (November 1978): 62.

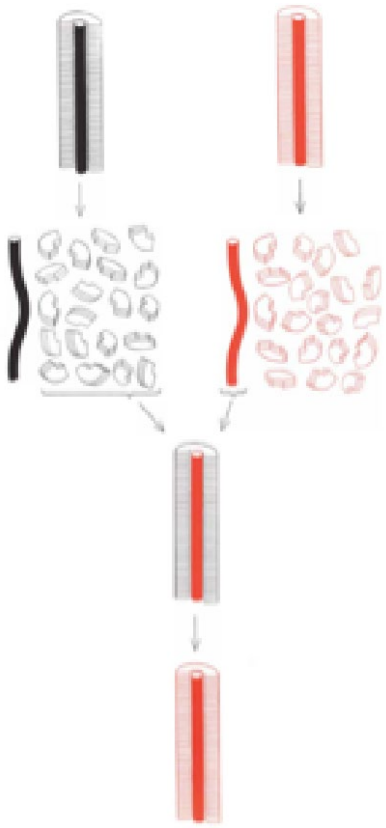

Figure 15: Creation of viral hybrid from two virus strains, and reproduction of created hybrid resulting in non-hybrid offspring (Fraenkel-Conrat, 1957)

The last example I would like to discuss about viruses as chemicals that are embryonic is a more recent experiment from 2002, when a group of researchers constructed a strain of poliovirus by downloading its genetic code from an online genomic database.[29] One significant feature about this experiment was the generation of an infectious virus *in the absence* of a natural template. In other words, this strain of poliovirus did not come from a preexisting poliovirus

[29] Jeronimo Cello, Aniko V. Paul, Eckward Wimmer, "Chemical Synthesis of Poliovirus cDNA: Generation of Infectious Virus in the absence of Natural Template." *Science* 297(2002):1016–1018.

molecule. Instead, using the genetic code of poliovirus they downloaded from a genomic database, researchers carefully constructed together the corresponding nucleic acids of the virus' genetic sequence. Though poliovirus is a single-stranded RNA molecule, because its genetic code was stored as in its corresponding DNA sequence in the genomic database, a DNA nucleic sequence was initially strung together. An enzyme called phage T7 RNA polymerase (originally derived from a virus that infects bacteria) was then used to produce the poliovirus RNA from this constructed sequence. This synthetic poliovirus RNA was then added to a "cell-free extract," which was made by centrifuging or powerfully spinning cells to distill and separate their inner components. A cell-free extract is not "alive" in that the integrity of the cells has been destroyed by centrifugation, but the proteins and other sub-cellular entities are still available for poliovirus to use to replicate. The synthetically created poliovirus was able to generate viral progeny, which was evidenced by the viral "plaques" or colonies visible on the cell-free extract, just like the "native" poliovirus that was not synthetically produced (labeled as "wild type" virus in the figure below).[30]

[30] The one difference between the "native" poliovirus and the "synthetic" poliovirus was that the latter produced far fewer viral progeny, i.e., plaques or "colonies" than the native or "wild" virus. Researchers speculated whether this may be due to an error in genetic construction of the originary complementary DNA strand generated from the genetic code downloaded from the database. I would be interested to learn whether the subsequent generations of the synthetic viral progeny also exhibited increasingly less viral infectivity, which could be interpreted as an "error" in the code, or, alternatively, signify something about the limits of this type of experiment (in that it is unable to produce a genuine primary form that for Ruyer marks the virus).

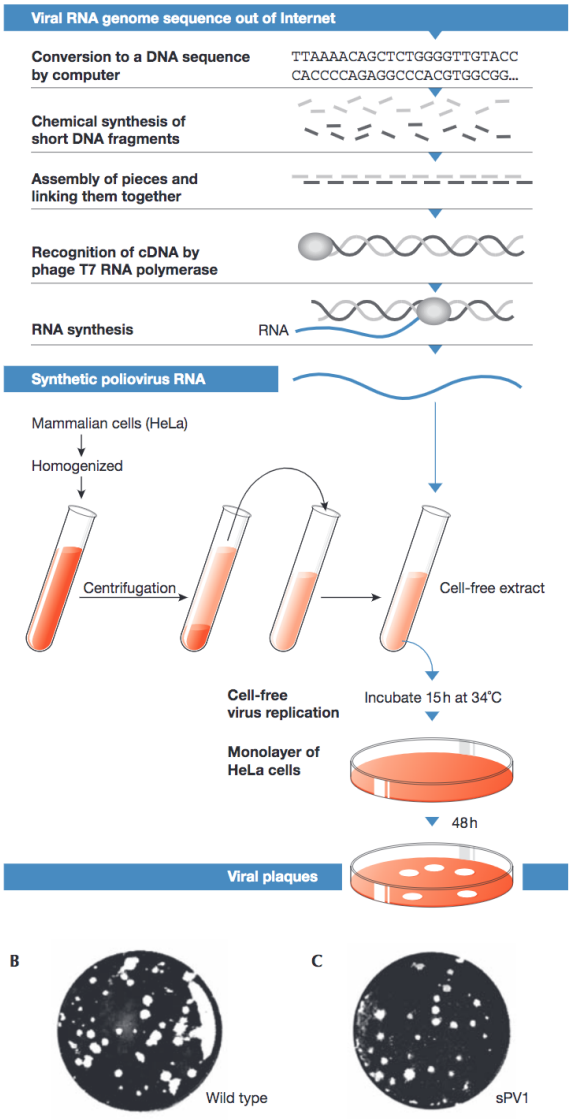

Figure 16: Synthesis of a poliovirus in the absence of natural template (Wimmer, 2006)

Viruses are a *theme* that begins to unfold or "play" when in its milieu. According to the authors, these "results show that it is possible to synthesize an infectious agent by in vitro chemical-

biochemical means solely by following instructions from a written sequence."[31] This led the lead researcher of this work to argue:

> The chemical synthesis of the viral genome, combined with de novo cell-free synthesis, has yielded a synthetic virus with biochemical and pathogenic characteristics of poliovirus. In 1828, when Wohler synthesized urea, the theory of vitalism was shattered. If the ability to replicate is an attribute of life, then poliovirus is a chemical $[C_{332,652}][H_{492,388}][N_{98,245}]$ $[O_{131,196}]$-$[P_{7501}][S_{2340}]$...with a life cycle.[32]

While the lead researcher of this experiment takes this to be the apotheosis of the idea of a virus as a chemical that has a life cycle, it should be noted that this virus is constructed using the enzyme T7 polymerase. It is this enzyme that generates the RNA code of poliovirus from the downloaded DNA template. The central role of this enzyme directly connects back to the central roles of enzymes in the *in vitro* experiments discussed in the previous chapter. That being said, this experiment does indeed give new force to the idea that viruses are chemicals with life cycles.

5.4 From Chemical Morphogenesis to Organic Morphogenesis

The activity of morphogenesis that marks all primary beings for Ruyer necessitates a concept of form that is neither static, geometric (i.e., spatial), nor external to matter. Ruyer's idea that there is inseparable relation between form and matter is a powerful critique of preformationism—here, form is a dynamic activity inherent to matter. As such, morphogenesis begins long before organic morphogenesis. Indeed, studying primary forms that are chemical

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[31] Jeronimo Cello, Aniko V. Paul, and Eckard Wimmer. "Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template. (Reports)." *Science* 297, no. 5583 (2002): 1016.
[32] Jeronimo Cello, Aniko V. Paul, and Eckard Wimmer. "Chemical synthesis of poliovirus cDNA: generation of infectious virus in the absence of natural template. (Reports)." *Science* 297, no. 5583 (2002): 1018.

beings makes clear the specific operations of form. This is because "in the molecular world, the chemical properties of bonds and formative properties are indiscernible."[33] He writes,

> In a molecule, all morphological change implies a chemical change: matter and form are strict correlates. The organic world simply manifests the same great fact: form is inseparable from matter. Living matter only ever appears as formed, just as the benzene molecule only ever appears, as matter, in its well-known hexagonal shape. Benzene is not an amorphous matter that comes to be 'informed' by the shape of the hexagon, produced like an Aristotelian form. *It is this form itself*, which is in turn derived from the modes of bonding of carbon and hydrogen. In the same way, biological forms arise without hiatus from molecular morphology. We do not yet know how the specific visible forms of cells are derived from molecular networks, but doubtless relations exist between molecular morphology and the morphology or organic morphogenesis already found in the chemistry of enzymes or the asymmetrical synthesis of organic compounds.[34]

A morphological change in a molecule always accompanies a chemical change; in this sense, "matter and form are strict correlates." In the twentieth century, science can no longer hold that "inanimate" matter is fundamentally different in composition than "animate" matter. This idea can be further revolutionized if one then contemplates how matter itself is dynamized for this continuity between the inorganic and organic to be possible. If the morphogenesis of living beings does not come from a vital principle (especially one that is only rooted in organic cells), then, Ruyer argues that we must extend verticalism—that is, thematic and formative activity—to chemical morphogenesis itself. The indissoluble connection between "morphological change" and "chemical change" in a chemical molecule signifies a key element of morphogenesis, one that must be kept in mind for the organic morphogenesis that such chemical morphogenesis can begin to unfold.

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[33] Ruyer*, Neofinalism*, 30.
[34] Ruyer, *The Genesis of Living Forms*, 31, emphasis added.

Ruyer is a rich resource to understand the genesis of living forms because of the ample attention he gives to theorizing the relationship between organic morphogenesis and chemical morphogenesis. He writes:

> Organic morphogenesis continues chemical morphogenesis and seems to put it into its service. Conversely, chemical behaviour is sometimes put to use quite directly, even at the highest level of organic life…[for example,] the movements of amoebae, which were thought to be a phenomenon of diffusion or surface tension, are more likely to be explained by the self-folding and unfolding of protein molecules in the amoeba. Like movement in the protozoa more generally, moreover, this constitutes a true comportment. A continuity can therefore be observed here, as before in the case of the virus, between chemical and biological comportment. Incidentally, contractile proteins also play many other roles, notably in the movement of vibrating cilia and in muscular contraction in general – so much so that human movement derives, in a quite direct fashion, from the contractile properties of molecules.
>
> But we should be wary of concluding that a disincarnated intention makes use of molecular behaviour, and thereby returning to a completely nominal vitalism. Ends and means are very difficult to distinguish in an organism precisely because the constituent individualities of a higher organic individuality, with its cycles of behaviour and complicated relays, are themselves assembled and transformed into agents in one of its cycles. When, lacking a tool for the job, people form up into a chain so that a bucket of water can be sent to extinguish a fire, they are also subordinated to a total behaviour: consciousness of the system envelops the conscious attention of each person as they pass the bucket to their immediate neighbour. In all collective behaviour, constitutive individualities are at once ends and means. What is gained, in human or even animal society of a high enough level, by the adjustment of instincts or conscious calculation, is gained at the molecular level through the indetermination of the individuality of the constituents in a system of interactions. This indetermination of individuality implies an indetermination of means and ends.[35]

I quote Ruyer at length here because he undertakes a detailed analysis of how the complex relationship between the chemical and the organic cannot simply be understood as a unilateral movement that only moves *from* the chemical *to* organic. Morphogenetic activity can be organic morphogenesis continuing chemical morphogenesis just as much as it can be chemical morphogenesis putting organic morphogenesis to use. The case of the amoeba in this regard is

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[35] Ruyer, *The Genesis of Living Forms*, 42-3.

especially interesting. If the unique way this organism is able to change shape—which allows it eat and digest without having a digestive system—is due to organic morphogenesis working in the service of chemical morphogenesis, then all primary forms are agents of activity. The theme that guides organic activity can use either chemical or organic morphogenesis (or both).

This is because at the border "between" the chemical and biological, there is an "indetermination of individuality" that allows for an "indetermination of means and ends." This indeterminate individuality is observed in viruses, as well as enzymes and proteins; in other words, in all "organisms" that exist at the border of what is chemical and organic. The line between what is a chemical substance and a primitive organism is never definitive. As a result,

> [t]his is why, for example, it is impossible to say whether the remarkable energetic properties of ATP molecules or chlorophyll are utilised by the molar organism because it requires substances that use or emanate energy or if ATP molecules and substances capable of photosynthesis are primitive organisms which are subsequently associated through more complicated cycles of functioning. Or rather, it is not a matter of choosing, and that both of the two hypotheses must in truth be accepted at once. A protein, or a virus with its chains of peptides and the attached amino acids, resembles a living tool – though not the pure tool of an organism, even if we consider the protein that has become an enzyme, or the virus integrated into a bacterium as a kind of gene. The extreme difficulty in deciding between theories of the virus as an autonomous, primitive organism and of the virus as a part of a ruptured cell is thus only a particular case of the same phenomenon.[36]

To reiterate a point I made earlier, if chemical beings exhibit thematic behavior, they are, then, agents of finalist activity. It is in this sense that they are primitive organisms. This embrace of the indetermination of individuality we see at the components of sub-cellular life reorients how organic activity is fundamentally understood. It does away with debates about whether nucleic acids, proteins, and other sub-cellular components are alive, and instead foregrounds a much more interesting orientation to the origins of life. Rather than try to directly pinpoint a protein or a

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[36] Ruyer, *The Genesis of Living Forms*, 43.

virus as a chemical used by a cell *or* an organism in itself, Ruyer affirms the duality here. Returning the question of what theory of memory would inform a non-binaristic theory of life, the duality of virus as both chemical and organism, as a "chemical with a life cycle," suggests that the origins of memory are more primordial than even the border zones where chemicals can behave as organisms.

5.5 Viruses and Reproduction: The Question of Memory

Throughout his discussion of the shift from a chemical to an organic mode of being, Ruyer draws attention to how viruses, due to their peculiar properties can be molecules as well as organisms, can act as a threshold between the molecule and the organism. He considers the abilities of phages (viruses that infect bacteria) to reproduce, as well as the correlation between viruses and genes:

> What yet remains mysterious is the question of knowing why certain molecules, genes and viruses have the property of reproducing themselves while, in general, ordinary molecules do not. Why, for instance, is a molecule of alcohol added to carbonated water unable to reproduce itself, even when all of its elements are found there?...The response will probably be able to be given when, on the one hand, the energetic conditions for the reproduction of molecules are better known and, above all, when chemistry will have been able to establish the developed formulae of virus molecules. It is highly likely, for example, that only certain types of chemical bonds involve *a true systemic unity* and also that only certain networks of these bonds can provide a complex molecule with an *individuality* capable of being imposed on neighbouring materials.[37]

Viruses embody the simplest kind of reproduction, and this ability may stem from the particular kind of individuality that can be engendered by specific chemical bonds.

Following Ruyer, we can say that viruses are specific kinds of chemicals that can self-reproduce. This characteristic differentiates them from other chemicals. While a machine can

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[37] Raymond Ruyer, *The Genesis of Living Forms,* 38.

reproduce a form, information, and, on the basis of information, another machine like itself, the limits of a machine for Ruyer are that "it cannot 'reproduce itself.'"[38] In contrast to producing another,

> 'to reproduce [oneself or] itself' designates an action, inconceivable outside of a field of 'absolute surface' in which the forms 'read themselves' by themselves, and can consequently 'read' the possible resemblance between themselves and their own limbs (that is, an analogous 'self' within their own numerical 'self'). After which, through an internal break, due most likely to the chemical substitution of localizing joinings for delocalized joinings, the two similar parts become autonomous and differ numerically. When a gene or a virus reproduces itself, in *seeming* to induce at a distance the formation of a proteinic chain resembling it, this 'at a distance' must be a quasi-distance analogous to that of the details of a field of vision, rather than a true distance of ordinary physics.[39]

Reproduction, like embryogenesis, occurs within a field of absolute surface. Viral reproduction, like all true reproduction, "is a division into two of an organic consciousness, not a fabrication of an organic machine by another organic machine."[40] He hesitates in his earlier work about whether viral replication invokes themes (i.e., memory), something that is obvious in the embryogenesis of higher organisms.[41] This is because viral reproduction can be understood through a Neo-Darwinist lens. Briefly stated, Neo-Darwinism is a conceptual synthesis that tries to marry Darwinian evolution (which emphasizes change) with Mendelian genetics (which emphasizes genetic stability).[42] For Neo-Darwinists, "the morphogenesis of a species is the accumulation of

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[38] Raymond Ruyer, "The Mystery of Reproduction and the Limits of Automatism." *Diogenes* 12 (1964): 54.
[39] Ruyer, "The Mystery of Reproduction," 54-5, emphasis added.
[40] Ruyer, "The Mystery of Reproduction," 55.
[41] Ruyer, *The Genesis of Living Forms*, 22.
[42] Ruyer is not alone in his charge that Neo-Darwinism cannot explain morphogenesis. Lynn Margulis was also highly critical of Neo-Darwinism. In a 2011 interview, she says, "Neo-Darwinists say that new species emerge when mutations occur and modify an organism. I was taught over and over again that the accumulation of random mutations led to evolutionary change—led to new species. I believed it until I looked for evidence." (Dick Teresi, "Discover Interview: Lynn Margulis Says She's Not Controversial, She's Right," *Discover* Magazine June 16, 2011, https://www.discovermagazine.com/the-sciences/discover-interview-lynn-margulis-says-shes-not-controversial-shes-right). Furthermore, Margulis also challenges the Neo-Darwinist

fortuitous mutations."[43] Indeed, viral reproduction *seems* to affirm Neo-Darwinism because here we are dealing with reproduction via division where "all structural mutation is naturally transmitted."[44] "We cannot maintain that the progress of morphogenesis, from the virus-molecule to the human being, is explained by an accumulation of errors in the duplication of the 'instructions' in the automated manufacturing of an automatic machine by an automatic machine."[45]

While one way to understand viruses as chemicals is through their ability to be crystallized, another understanding becomes possible if we consider the relation between chemicals and temporalized activity—in other ways, when we deploy a more complex concept of "chemical." The particular kind of chemical nature of viruses when they exist as crystals brings us further away from an understanding of how chemical morphogenesis may lead to organic morphogenesis. In contrast, what may lead towards an understanding of the mode of chemical morphogenesis to organic morphogenesis is if we consider the role and force of temporality, and how it relates to Ruyer's conception of nature more broadly. Following developments in quantum chemistry that move away from a strict valence-based structure of atoms—which relies on a model of the atom as a miniaturized solar system with a central nucleus that has fixed orbit of electrons revolving around it—Ruyer argues that "chemical substances as characterised less by a structure than by an ensemble of structural states or *structural behaviors*."[46] In other words, the atom itself is a structuring activity in touch with its form. An example of this is how carbon,

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idea that evolution occurs through a slow "gradualism," arguing that there is no evidence of this "slow gradualism" in the fossil record.

[43] Ruyer, *The Genesis of Living Forms*, 21.
[44] Ruyer, *The Genesis of Living Forms*, 22.
[45] Ruyer, *The Genesis of Living Forms*, 25.
[46] Ruyer, *The Genesis of Living Form*, 35.

which has the capability to form four bonds, "is not a structure but a *structuring activity*."[47] It cannot be understood as a rigid structure that is simply geometric. The positions of electrons in the carbon atom cannot be precisely pinpointed. It instead involves "electron density maps which represent, depending on the profile of the level, the means of structuring comportment." This brings Ruyer to argue that "verticalism, the dynamic deployment of functional elements is primordial, *in chemistry as in biology*."[48] "Verticalism" is synonymous with thematic formation. To say that verticalism is primordial in chemistry as much as it is in biology means that thematic, self-making activity—in other words, what we directly witness in cellular life—exists in the primary forms of chemistry just as much as biology. Thematic activity (what we could call an incorporeal theme) subsists in chemical beings just as much as biological beings. This temporalized structuring thematic activity that marks chemistry conditions or "prepares" the possibility of a kind of hereditary memory of viruses.

> The typical, individualised behaviour of the virus, its active and combative perseverance, appears to be of the same nature as the individualised comportment of a benzene molecule, a molecule of water or of any molecular, atomic or subatomic individualities. The temporal, and not simply geometric, aspect of bonding activities at every level *prepares* for the 'historical' and 'hereditary' subsistence of the virus, which is wrongly taken to be a simple molecular structure in space but which reveals their vertical 'temporalisation' such that they are capable of passing from the virtual to the actual through a kind of reproductive mnemic comportment. At first glance, it appears more economical and scientific to explain the reproduction of the virus in terms of a spatial 'moulding', but we must ask if we are not buying into a bad deal. For whatever the particular path the immensely complex process of the reproduction of the adult organism takes, the metaphor of spatial moulding is practically worthless. What is really economical is to redeploy in each case the modern category of bonding through temporalized structuring activity drawn from the level of molecular reproduction.[49]

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[47] Ruyer, *The Genesis of Living Form*, 36.
[48] Ruyer, *The Genesis of Living Form*, 36.
[49] Ruyer, *The Genesis of Living Forms,* 38, emphasis added.

Indeed, activity and being are one and the same: "*For the atom as for the living being and the conscious being, we 'cannot separate what matter is from what it does*.'"[50] This is to say that the structure of matter cannot be separated from its temporal behavior.[51] Because a "rhythm of activity" is always inherent to matter, matter can never be instantaneous. "A physical element is nothing if it is instantaneous, if it is not a certain prolonged rhythm of activities."[52] This rendering of matter challenges the idea of time as an empty dimension or "empty and foreign frame."[53] Instead, "the time of action is inherent to this action as a temporal melody. This amounts to saying that it can only be conceived as the mnemic rhythm of activity. The physical rhythms are indiscernible from a memory."[54] Memory for Ruyer is the directionality and form-given process of self-creation according to a theme.

This ability to reproduce connects to memory, but in a very specific way. Though viruses can call on or invoke memory to reproduce, evolutionary memory in itself does not begin with organic beings such as viruses. The situation is more complex. For Ruyer, physical beings are not devoid of memory. To be clear, "physical beings" here are different from the more common objects of chemistry and Newtonian-Einsteinian physics, which are secondary forms or aggregates. Physical beings—in other words, primary forms such as atoms and molecules—are not devoid of memory because, as I mentioned above, their physical rhythms are *indiscernible* from memory. Memory is not invented *de* novo at some point in between chemical or organic morphogenesis (the space that liminal entities like viruses occupy). Rather, the difference is that

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[50] Ruyer, *Neofinalism*, 148, citing Louis de Broglie, *Continu et discontinu en physique moderne* (Paris: Albin Michel, 1951), 66, 74.
[51] Ruyer 148, citing Robin George Collingwood, *The Idea of Nature* (Oxford: Clarendon Press, 1945), 146.
[52] Ruyer, *Neofinalism*, 149.
[53] Ruyer, *Neofinalism*, 149
[54] Ruyer, *Neofinalism*, 149

in physical beings there is a *lack* of *detachment* of memory from temporality. This results in these beings not generating a "transspatial reserve," a virtual domain where memory can become a resource for future thematic activity. On this Ruyer writes:

> The main difference between physical beings and the most complex organisms does not probably derive from the instantaneity or the absence of memory in the former but from *a lack of detachment of this memory*, which in physical beings is always inherent to the rhythm of activity, which is only ever "the form in time" and does not constitute a transspatial "reserve" clearly detached from the actual...In all organisms proper, organic memory constitutes specific potentials that can be reincarnated in innumerable individuals. In physical beings, no enrichment of this kind is found. The semisubstantialization of activities into "mnemic beings" does not take place for physical beings.[55]

Physical beings are not static precursors. They enjoy a structuring activity that coincides with temporality, and thus, for Ruyer, also with memory.[56] Physical beings neither lack temporality or memory. The key difference for Ruyer is that the flow of time inherent to matter does not automatically generate memory that can act as a future virtual reserve. Virtuality requires a *detachment* of memory from temporality for it to begin its "life" as a mnemic theme that can be invoked to guide future becoming in spacetime. The *lack of detachment* of memory (rather than the lack of memory itself) results in the temporal, rhythmical activity of physical beings not generating a transspatial reserve.[57]

When memory *does* detach itself from the temporality that constitutes physical beings, it constitutes a transspatial "reserve" that removes itself from the actual and thus able to become organic memory proper that can guide future spatiotemporal becomings. In a transspatial domain

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[55] Ruyer, *Neofinalism*, 149, emphasis added.
[56] Ruyer, *Neofinalism*, 149.
[57] Ruyer's conception of memory differs from memory is automatically preserved for Bergson. "A memory is always necessarily an idea. Bergson's assertion that every actual automatically becomes a memory is false. The actual becomes a memory only when it is imbued with "sense," which renders it incorruptible" (Ruyer, *Neofinalism*, 128).

of themes, reproduction becomes virtually infinite (though it is restricted by "available material of realization"). Invention here is in direct relation to, or occurs in contact with, a virtual that in itself can never be exhausted. Because it calls on memory from the transspatial domain, the reproduction of viruses, like that of cells, is (potentially but not actually) infinite:

> In the psychobiological order and in the *number* of actualizations seems indifferent; it seems to cost nature nothing and is only limited by the occasion or the available material of realization. Viruses, protean-viruses, unicellulars, and the embryos of superior organisms, like the mnemic evocations or the evocations of ideas, can be divided and multiplied to infinity. The indifference *of the number* of actualizations perfectly responds to the indifference *to the number* of essences and themes.[58]

This idea weaves into contemporary insights of viruses as genetic engineers that may have had a central role in the beginnings of genetics in the beginnings of cellular life, but it does so in a way that speaks to the question of memory that does not equate or locate memory squarely in material genes, or, for that matter, in materiality. Something more than just the material of genes must explain the ways in which organisms appeal to or call on memory to guide their formations, and with which they invent.

If we return to the question of what is the relation between viruses and invention, one possible way inventiveness can be accounted for is through the idea of mutations. In contemporary scientific literature, viruses are linked to mutations: they generate novel genes that drive evolution by generating new proteins and capabilities that are transferred to its hosts when there are symbiotic mergers. A mutation—which can arise from: an error in replication or repair, or due to a genetic substitution, insertion, or deletion—can be understood as a structural change

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[58] Ruyer, *Neofinalism*, 132.

that may or may not have an effect on an organism's phenotype (i.e., its observed characteristics). Mutations can in theory be positive or negative (though random mutations are likely to be negative much more than positive; this is Ruyer's critique of Neo-Darwinism).

According to Neo-Darwinism, the morphogenesis of species is the accumulation of fortuitous mutations and the elimination of mutations "incompatible with survival."[59] In this emphasis on mutations (the accumulation of 'advantageous' mutations and the removal of negative mutations), individual morphogenesis within a Neo-Darwinian framework is wholly reduced to the question of mutation. Ruyer rejects the emphasis that Neo-Darwinism, because of its strong *resistance* to understand "the morphogenesis of species as a *thematic* invention" or the work of memory, places on *mutations* in the generation of species—that is, he critiques the idea that undirected mutations can randomly benefit individuals and species.[60] He writes:

> If each new being, in each new generation, were produced through a sort of tracing, everything would make sense. It is *possible* that it happens a little like this in the virus – since it reproduces by division, all structural mutation is naturally transmitted. But it is not at all the same for multicellular organisms, which must reconstitute adult forms in the course of a long embryogenesis and which do so, as we will note, on the basis of very schematic forms. If, for example, a human being is a simian *plus* mutations, why is the embryonic human less than a simian and even less than a fish or a vertebrate? If mutation is, by origin and nature, completely mechanical, entirely 'structured' in the properly spatial sense of the word, how can it remain virtual during the first stages of embryogenesis?[61]

Building on the Neo-Darwinian refusal to understand the morphogenesis of species as a thematic invention, mutation in this context here is mechanical and completely separate from thematic activity and memory. Viral replication may be the only case for Ruyer in which the mechanist mutation of morphogenesis *may* be plausible. From multicellular organisms onwards, and

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[59] Ruyer, *The Genesis of Living Forms*, 21.
[60] Ruyer, *The Genesis of Living Forms*, 21.
[61] Ruyer, *The Genesis of Living Forms*, 22, emphasis in original.

especially in the case of animals, morphogenesis must be the continuation and further unfolding of thematic behavior.

The study of viruses as chemicals accomplishes two almost paradoxical effects. First, in a Ruyerian sense, it entails a continuity between physical and chemical forms on the one hand and organic forms on the other. This is in a way to be expected, as all three are primary forms that enjoy a certain kind of self-consistency that allows them to be dynamic self-making activities. Ruyer is not the first to fashion a continuity thesis of some sort in relation to the origins of life. Indeed, a continuity thesis undergirds all of twentieth-century origins research. The continuity in the latter, however, focuses exclusively on a continuity of chemistry and biology (in the beginnings of biochemistry), but it does *so without addressing memory or heredity*, or any sort of virtual. Questions of heredity in the sciences almost always begin with genetics. What is significant about Ruyer's "continuity thesis" of memory and heredity is that it begins before cellular life. It is produced from the temporal activities of primary forms creating a virtual that future embryonic becomings can call upon and invoke.

Studying viruses as chemicals in contemporary virology also coincides with an engineering ideal that runs through arguably all of the current life sciences, an ideal or desire that is further strengthened every time there is new research that demonstrates the "chemical" nature of viruses. The "chemical" nature of viruses allows for the laboratory genesis of viruses from different component parts. This engineering of viruses—either from carefully denatured or disassembled parts, or from the generation of new virus particles by constructing their genetic codes using enzymes and subsequently planting them in a cellular milieu—is a sign of not only the increasing ways life can be manipulated and controlled, but also evidence of the embryonic qualities viruses embody as primary forms. The memory that serves as a virtual reservoir for

chemical and organic morphogenesis that conditioned the possibility of the emergence of life is the reason why the scientific manipulation of life is possible to such a large degree.

6. Conclusions

6.1 To be Expected?

Rather than an improbable, chance event, here on Earth and across the universe, life is increasingly understood as a natural expression of matter. Over the course of the twentieth and into the twenty-first century, the relation between matter and life in the context of the latter's emergence has shifted from a difference in kind to a difference in degree. The two central ways this shift has occurred is through theories of order rooted in self-organization, and geologically centered or "habitat-based" origins of life research. Self-organization was originally coined by Immanuel Kant to designate the specific self-forming properties of life that distinguish it from the nonliving. It therefore grounded a stark division between matter and life.[1] In contrast to Kant's division, theories of self-organization put forth in the twentieth century reimagined the capacities of matter in far-from-equilibrium conditions, and as a result, reframed the relation between matter and life. Theories of self-organization stress that natural selection cannot completely explain the evolution of life, especially its origin.[2]

The discovery of deep sea vents transformed where and how the emergence of life was thought to have occurred. These geological sites were the first "habitat-based" ecological theories of the origin of life. Because these vents hosted entire ecosystems near them, deep sea vents were

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[1] For a history of self-organization, see Evelyn Fox Keller, "Ecosystems, Organisms, and Machines," *BioScience* 55, no. 12 (2005): 1069–1074, as well as Eric Karsenti, "Self-organization in cell biology: a brief history," *Nature Reviews Molecular Cell Biology* 9 (2008): 255–262.

[2] In fact, scientists such as Christian de Duve argue that natural selection came into play during the second phase of life, after an initial phase that was solely composed of the emergence of self-forming chemistry, one that probably established the RNA world (Christian de Duve, "Life as a cosmic imperative?" *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* 369, no. 1936 (2011): 620).

proof that life does not require sunlight to exist. They also simultaneously demonstrated the necessity of taking seriously the far-from-equilibrium geological and geochemical conditions that not only can sustain current life, but could provide the conditions of its initial emergence. As British biochemist Nick Lane reminds us, "[t]his bioenergetic perspective provides an insight into the evolution of life, not just on Earth but also elsewhere in the universe. The origin of life is theoretically probable on any wet rocky planet, as the common geological process of serpentinization is predicted to give rise to alkaline vents on a global scale."[3] Habitat based ecological theories rooted in the logic of deep sea-vents now serve as a model NASA uses to search for life elsewhere, both within and beyond our solar system.

This habitat-based approach to finding life has led to speculation that it could exist on other celestial bodies that, like Earth, have liquid oceans and are geologically volatile in their interior.[4] In 2005, NASA's Cassini space probe found plumes of water vapor being powerfully ejected out into space from Enceladus, Saturn's sixth largest moon. Beneath its icy exterior, Enceladus has a massive ocean that touches an inner rocky crust that is porous. This permeable crust allows for water to move in and through it, generating energy and heat in the process. Hydrothermal activity at the rock-water interface could provide the environmental milieu of disequilibrium for cellular life to begin, a maternal beginning that once again that does not rely on the Sun. Here, just as in deep sea alkaline vents, the process of serpentinization is thought to be

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[3] Nick Lane, "Chance or Necessity? Bioenergetics and the Probability of Life," *Journal of Cosmology* 10 (2010): 3304. Serpentinization is the transformation of certain metallic-containing rocks to a specific kind of rock called serpentine, all of which occurs as an effect of the movement of water through these rocks. This process releases hydrogen gas (H_2) in the process. Hydrogen gas can provide the raw materials for the generation of amino acids, and is also a vital food source for prokaryotic lifeforms (which use H_2 to produce methane (CH_4)).

[4] H_2O is ubiquitous across the universe; the problem is that it is in the form of ice. *Liquid water* is much more difficult to find, and an absolutely necessary for the chemistry of life.

ongoing, generating hydrogen gas which can serve as a food source for single cellular life (analogous to how microbes metabolize hydrogen gas at deep sea events on Earth). This, combined with how organic compounds have been detected on Enceladus, make this volatile moon possibly the most habitable world for life, outside of ours.[5]

Other searches for life that also are habitat based follow a different approach, though they maintain the idea that life is a natural expression of matter. One example is the scientific interest in Titan, Saturn's largest moon. The search here differs from life as we know it on Earth because Titan is covered with ice as it is much too cold for liquid water to exist. In lieu of liquid water, scientists speculate whether the hydrocarbon ocean of *liquid methane* or *ethane* exists under its icy surface could support *methane*-based life.[6] In fact, physicist Jonathan Lunine has suggested that Titan's "exotic" planetary environment compared to Earth is a useful place to test the idea if life "is a common outcome of physical and chemical processes in the universe."[7]

This is all to say that throughout the universe, if given the right ingredients and the right conditions, life is increasingly becoming understood as something that could *not* have *only* arisen on Earth. The guiding mantra for scientists who search for life's origins in deep sea ecologies that have analogues in outer space is the idea of "the emergence of life as an *ordinary* event."[8] Habitat-based ecologies—which are adept at theorizing the geochemical disequilibrium

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[5] Christopher P. McKay, Ariel D. Anbar, Caroly Porco, and Peter Tsou, "Follow the Plume: The Habitability of Enceladus," *Astrobiology* 14, no. 4 (2014): 252.
[6] While Titan could indeed provide such a case study, this particular scientific search for life assumes that the medium of life as we know it (water) can be easily replaced by another liquid medium. Some scientists remain skeptical about the idea of a liquid other than water as the solvent for life, especially because no other liquid has all of water's unique properties that make it such an ideal solvent.
[7] Jonathan I. Lunine, "Saturn's Titan: A Strict Test for Life's Cosmic Ubiquity," *Proceedings of the American Philosophical Society* 153, no. 4 (2009): 403.
[8] E.L. Shock, J.P Amend, and M.Y. Zolotov, "The Early Earth vs. The Origin of Life," in *Origin of the Earth and Moon*," (Tucson: The University of Arizona Press, 2000), 530.

conditions necessary for life—seamlessly coalesce with theories of self-organization. Manfred Eigen, a Nobel Prize Winning German physicist, unites these two ideas when he argues that, "[t]he evolution of life, if it is based on a derivable physical principle, must be considered an *inevitable* process, despite its indeterminate course ... it is not only inevitable 'in principle' but also sufficiently probable in a realistic span of time. It requires appropriate environmental conditions (which are not fulfilled everywhere) and their maintenance. These conditions have existed on earth and must still exist on many planets in the universe."[9] Thus rethinking the relation between matter and life, and theorizing the conditions of emergence have vastly reshaped how we understand the beginning of life, as well widens our horizons of where we think it may exist.

These fundamental restructurings of how we understand life to have emerged and where we expect to find it have had direct effects on how scientists understand the human's existence. In a way, the central question motivating the study of life's origins concerns the human's place in the world, specifically whether the human's existence was expected in the universe. Thinking about this question, in 1970, in a text on evolution called *Chance and Necessity*, Nobel prizing biologist Jacques Monod famously wrote: "The universe was not pregnant with life nor the biosphere with man. Our number came up in the Monte Carlo game. Is it any wonder if, like the person who has just made a million at the casino, we feel strange and a little unreal?"[10] For Monod, if life as a coherent and reproductive entity came about through random chance, then it is highly unlikely to be a common occurrence. And *if* that is true—in other words, if randomness is

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[9] Manfred Eigen, "Selforganization of Matter and the Evolution of Biological Macromolecules," *Naturwissenschaften* 58 (1971): 519.
[10] Jacques Monod, *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology* (New York: Vintage Books, 1972), 145.

the method that brought about life—then the human is inevitably alone in the universe, and its existence is entirely contingent.[11] We are here an historical effect of evolution, therefore our existence could be understood as accidental. But we now think that the orientation of particles as well as the forces that regulate them are not random. Writing a quarter of a century later, theoretical biologist Stuart Kauffman continued this line of questioning, but provided a different answer. Arguing that natural selection alone cannot explain the origin and evolution of life, Kauffman put forth the idea that there are self-organizing laws of nature that work in tandem with natural selection. These two principles combined explain life's existence in the universe, which, according to Kauffman, we take to mean the human's. Theories of self-organization—the idea that matter takes on self-forming properties at particular environmental conditions—have fundamentally reshaped how we understand the origin of life, and by extension, our "place" in the universe. Kauffman writes,

> If we are, in ways we do not yet see, natural expressions of matter and energy coupled together in nonequilibrium systems, if life in its abundance were bound to arise, not as an incalculably improbable accident, but as an expected fulfillment of the natural order, then we truly are at home in the universe.[12]

Kauffman here is recognizing the particular aspects of life that make its eruption an expected event. Though he is undoubtedly a key theorist of self-organization, Kauffman's argument suffers

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[11] The Human's relation to the world has often been thought in terms of the ethical question of whether there is purpose in nature, or who or what organizes Nature in a godless universe. More specifically, there has often been a deep philosophical tension between human teleology (the idea that humans have a purpose) and teleology existing in nature (Ruyer, *Neofinalism* 22). By the mid twentieth-century, there is a shift in biological treatises on the nature of life from the language of teleology to *teleonomy*, which is the idea that nature acts *as if* there is purpose in the natural world. Here, an organism's directedness toward a goal or end is only an appearance. Despite attempts to reserve *telos* for humans, teleonomy still creates a crisis for Humanism. Monod adopts a teleonomic perspective toward evolution in *Chance and Necessity*.

[12] Stuart Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (Oxford and New York: Oxford University Press, 1995), 20.

from an extreme case of anthropomorphism that warps his logic: it equates life's ripe potential to emerge in the universe with the human's existence in the universe, and does so by collapsing the concept of life and its origins with that of the human.[13] Life is indeed a kind of virtual cosmic imperative, but this quality of life cannot be equated with the human.[14] It is in fact dangerous to think this way. To make the arrival of the human expected is to reduce the plurality of life in all

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[13] One of Kauffman's central claims about the origins of life is that life did not begin from a more "simple" form that later became more complex. The eruption of life for Kauffman embodied a kind of complexity. I firmly agree with this claim. I take issue with Kauffman's continual collapsing of the expected emergence of life in the universe with the human. This is the central ethos of *At Home in the Universe*. There are additional tenets of his argument that I find problematic, and which directly inform his understanding about the expectedness of human existence. One critical point is his view that life, at its origin, exhibited a holism (which he connects to Kant's view of organisms as wholes). Kauffman argues that the self-organizing autocatalytic sets that conditioned the emergence of life can be both explained by their parts just as their parts can be explained by their whole. Holism, Kauffman contends, is central to how we understand life, which, again, for him immediately means the human: "Most important of all, if this [i.e., the holistic property of life that autocatalytic sets embody] is true, life is vastly more probable than we have supposed. Not only are we at home in the universe, but we are far more likely to share it with as yet unknown companions" (69). See also how the question of there being self-organizing order in the universe is always in relation to "humanity's stance:" "[t]he living world is graced with a bounty of order. Each bacterium orchestrates the synthesis and distribution of thousands of proteins and other molecules. Each cell in your body coordinates the activities of about 100,000 genes and the enzymes and other proteins they produce. Each fertilized egg unfolds through a sequence of steps into a well-formed whole called, appropriately enough, an organism. If the sole source of this order is what Jacques Monod called "chance caught on the wing," the fruit of one fortuitous accident after another and selection sifting, then we are indeed improbable. Our lapse from paradise—Copernicus to Newton in celestial mechanics, to Darwin in biology, and to Carnot and the second law of thermodynamics—leaves us spinning around an average star at the edge of a humdrum galaxy, lucky beyond reckoning to have emerged as living forms. How different is *humanity's stance*, if it proves true that life crystallizes almost inevitably in sufficiently complex mixtures of molecules, that life may be an expected emergent property of matter and energy. We start to find hints of a natural home for ourselves in the cosmos" (71, emphasis added). To be fair, Kauffman does, at one point, understand humanity as both expected and *ad hoc* give how self-organization and natural selection are the two concepts that shape life, but here, again, he equates life with the human: "Whence the order out my window? Self-organization and selection, I think. We, the expected, *and* we, the ad hoc. We, the children of ultimate law. We, the children of the filigrees of historical accident" (185, emphasis in original).

[14] Christian de Duve, "Life as a cosmic imperative?" *Philosophical Transactions: Mathematical, Physical and Engineering Sciences* 369, no. 1936 (2011): 620-623.

its forms to one being. This equivocation of life with the human is in many ways the positing of a universal subject at the center of the universe, and therefore the continuation of a (phallocentric) tradition that privileges one particular kind of subject as *the* (invisible) and universal over and above all other subjects, both living and nonliving.

Where does order come from? What is the place of life—and by extension—the human? Furthermore, what are the dangers embedded in the idea that humans were bound to exist? What else might be understood as inevitable? Was the rise of capitalist-colonialism that began in 1492, and its accompanying horrors, expected? Were patriarchy and racism inevitable? Our origin may have been expected in the sense that life shares with all its forms a common unity at its origin, and because life is a cosmic orientation, its possibility to actualize is therefore virtually potent, as well as polyvalent, capable of generating many values. From this origin, life diverged into a multiplicity of lines that, even today, continue to differentiate, including the line that ends with the human. The human can trace its lineage back to this origin, but this does not mean that the human can use the life's latent virtuality in the universe to reify its existence. Though this dissertation in many ways thinks about the sources of order, and seeks to think origin and evolution beyond simple selection, I have deep reservations about Kauffman's declaration that we are the expected. What may be more useful to thinking life than unexpected pompousness—in other words, the rather pompous assertion of how could "I" *not* exist—is to remember the precarity of the Human. We are the "end" of evolution in more than one sense.

Though I do not disagree that life is in many ways expected, that it is an "ordinary" or "expected" event given the right conditions, I do not think that this immediately suggests that the human was expected. What *does* seem to be expected across the universe is single-cellular prokaryotic life. Multicellular eukaryotes like ourselves are in some way still exceedingly contingent because we would have not been possible had not it been for an unexpected

symbiogenetic event: the mitochondria in our cells that keep us alive by working to maintain such significant states of disequilibrium are *the* major reason complex life was able to evolve. Without an ancient symbiogenetic merger of an archaeal and bacterial cell, all higher forms of complex life would have never evolved. This is to say that though life is a natural expression of matter, life cannot be collapsed with the human. In fact, the human's existence, along with all complex multicellular life, was entirely a result of a chance encounter. Complex multicellular life arose through the unforeseen event of endosymbiosis, an evolutionary event in which eukaryotic (complex, organelle and nucleus-bounded) life was created by one prokaryotic cell consuming, but not destroying, another. This partial digestive act transformed the life's inventive capabilities by providing with a robust energetic reservoir. On this, Nick Lane, writes,

> If the evolution of complexity depends on a rare and stochastic event, that explains why natural selection does not continuously give rise to eukaryotic complexity in prokaryotic populations. The unique acquisition of mitochondria by a prokaryote transformed the course of evolution. By permitting cells to expand their cell volume and genome size without a crippling energetic penalty, eukaryotes could, and did, accumulate genes, ultimately the basis of complexity. It makes sense that prokaryotes are almost universally small and genetically streamlined, showing little tendency to evolve eukaryotic complexity. It makes sense that multicellular eukaryotes only arose once in 4 billion years of evolution. And it makes sense that the acquisition of mitochondria released the first eukaryotes from the energetic constraints that limit all prokaryotes, enabling the evolution of genetically and morphologically complex life on Earth.[15]

Natural selection cannot in itself give rise to complex, eukaryotic life because the latter's emergence was entirely dependent on one microscopic organism consuming, but not killing, another microbe that could generate massive amounts of energy (or, more precisely, significant states of disequilibrium). The acquisition of this cell (what became the organelle known as the mitochondria) allowed for complex morphology to form. While single cellular bacteria excel at exploring the virtuality of "genetic space"—they invent new genes at a rapid pace—bacteria are

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[15] Lane, "Chance or Necessity?," 3304.

restricted by their energetic constraints. This is what Lane means when he says that it makes sense that prokaryotic life does not evolve into eukaryotic life; it is not a matter of one form of life being less "intelligent" than other but rather because the latter form of life was able to acquire (through symbiosis) the energetics complex morphological life requires to form. Without this chance event, no mushroom, plant, animal (including human) life would have been possible. This prompts Lane to say that "[t]he unavoidable conclusion is that the universe should be full of bacteria, but more complex life will be rare – and perhaps surprisingly similar to us. Aliens will have mitochondria too."[16] Contra Kauffman, life in prokaryotic form is to the expected, not the human (or any other form of complex multicellular life). *If* complex life was found elsewhere, it would be surprisingly similar to us because it too would have mitochondria (or organelles akin to mitochondria). Moreover, these organelles would be found within a larger organismic body as the result of an endosymbiotic event, similar to the origin of complex life on Earth.

Origins of life research, like the search for life across the universe, simultaneously centers and decenters the human. Though we are asking where we come from, at the same time the forces that make us possible and condition our existence make us feel uneasy *if* they prove that we are contingent. The ethical questions in origins of life research are always informed and inflected through a human frame. In this dissertation, I have placed pressure on whether the first ethical concern regarding the emergence of life should be thought in relation to the human. All of this must be done without privileging or centering the existence of the human. I argue this creates what later becomes an insurmountable problem rather than an interesting question that invites us to consider the ontological and ethical implications of the emergence and evolution of life. Having the human as a silent specter in the emergence of life also creates anachronistic problems,

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[16] Lane, "Chance or Necessity?," 3304.

especially if the origins of life is somewhere between 4.1 and 3.7 billion years ago and the evolution of humans, by contrast, occurred only around 2 million years ago. It is anthropomorphic to an extreme to theorize life's emergence around the human**.**

In this regard, I have turned to philosophers and scientific research in the previous and current century to theorize a philosophy of the origins of life that is resolutely non/human. Though a non/human approach to the origins of life does not erase the human, it does significantly decenter it. This decentering is crucial to develop a feminist philosophy of the origins of life because it thinks with evolutionary concepts that do not begin, or even end, with the human but instead are the conditions of its emergence. In addition to destabilizing the role of the human, *The Conditions of Emergence* teases out the theoretical implications of scientific research in which there exists an underlying desire to conceptualize *beyond* the assumption that the natural world operates through hierarchical dichotomies. The common thread that runs through the philosophies and scientific research I have addressed is their undercutting of dualisms, such as those between mind and body, matter and memory, life and matter, active and passive, and especially that of living and nonliving.

NASA seems confident that it will find life on another world in the next two or three decades. I share and welcome this enthusiasm. It could be entirely likely that life has had more than one origin in the universe. The "raw" organic ingredients for life abound in the universe. When the Murchison Meteorite landed in Murchison, Victoria, Australia in 1969, scientists found the meteorite rich in amino acids and hydrocarbons.[17] Though some may argue that organic compounds could have been seeded from outer space, what this signifies even more broadly is

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[17] Keith Kvenvolden, James Lawless, Katherine Pering, Etta Peterson, Jose Flores, Cyril Ponnamperuma, Isaac R. Kaplan, Carleton Moore, "Evidence for extraterrestrial amino-acids and hydrocarbons in the Murchison meteorite," *Nature* 228, no. 5275 (1970): 923–926.

that the chemical ingredients for life permeate the universe. It is not the chemical precursors of life that seem to be lacking. Though life may be a cosmic orientation, this does not mean that the human can (re)create life and bring about *de novo* cellular emergence. In other words, we cannot scientifically generate life without preexisting cellular parts. This may mark the limits of the human, and, by extension, the limits of biopower. Though the chemical precursors of life all seem to be present almost everywhere, according to a team of quantum biologists, "a much more difficult question is how the first living systems may have emerged from these prebiotic molecules, if at all...we have not yet been able to synthesize even a small functional peptide from basic components, and are still a long way from understanding exactly what distinguishes a collection of molecules from the collection of molecules that make up a living system…"[18] If the situation were to arise where life was found on another celestial body before it could be made "from scratch," what would this signify?

While one possibility could be that life has not been generated yet,[19] another possibility, that I will consider here, is the idea that perhaps we cannot create life *de novo.* Life, in its origin, is an expected eruption, but not one that can be manufactured by humans. It cannot be made *de novo* in a laboratory without preexisting life. Though life and matter are not opposites, and though both science and philosophy recognize the need to rethink matter and life's relation, perhaps our inability to create life in its cellular form signifies the particular qualities of life that characterize it as such. Life is endlessly fungible, manipulable, and controllable, but the limits of

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[18]Adriana Marais, Betony Adams, Andrew K. Ringsmuth, Marco Ferretti, J. Michael Gruber, Ruud Hendrikx, Maria Schuld, Samuel L. Smith, Ilya Sinayskiy, Tjaart P. J. Krüger, Francesco Petruccione and Rienk van Grondelle, "The future of quantum biology," *Journal of the Royal Society Interface* 15 (2018): 20180640.

[19] This is the position of many scientists, including Nobel prize winning biologist Jack Szotak at Harvard Medical School. See Jack Szostak, David P. Bartel, and P. Luigi Luisi, "Synthesizing life," *Nature* 409 (2001): 387–390.

biopower seem to be that life cannot be created from scratch—which is to say it cannot be created from the outside. Life creates itself embryonically, even at the level of the atom. What seems to be possible is the human creation of a virus through a code, which speaks to how we understand life "best": in its most reduced (and manipulable) form of a genetic code. While viruses can be synthesized by stringing together their genetic code (a phenomenon I explored in the fourth chapter), the emergence of a virus still requires the milieu of a living cell (or a "cell-free extract" that has internal cellular components without cell membrane). The theme of a cell provides the conditions for a virus to emerge. In other words, it requires parts of a living cell (or what were once a living cell), and is therefore not life "made from scratch."

In fact, I am more confident that we will find life on other celestial bodies, whether within or beyond our solar system, than create life "from scratch" itself. Perhaps life cannot be created *de novo* because there is a particular quality that inheres in life, one that cannot be manufactured. This is indeed Raymond Ruyer's central thesis, whose ideas I closely thought with in chapters three and four. For Ruyer, "[t]he fact that it [i.e., a part] functions, once formed, through step-by-step actions implies precisely that it cannot be formed in this way."[20] This critical insight, which speaks to the *specificity of primary or "living" form,* combined with his argument that there is a virtual continuity of life that stems back to the origins of universe itself, is precisely why there no longer seems to be an insurmountable gap between the inorganic world and the cell. The dictum of spontaneous generation—*Omnis cellula e cellula* [all cells come from cells]—cannot generate a theory that addresses what physical and chemical world and life share. [21] Instead of arguing all cells must come from a cell, what is more provocative and conceptually

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[20] Ruyer, *The Genesis of Living Forms*, 21.
[21] Virchow, *Cellular Pathology*, 27.

generative to think with is *Omne vivum ex ovo*: all life [is from] an egg.[22] This is because there is something about living form that always remain embryonic. This embryonic quality begins before cellular life, as it *is* the structuring activity that is the atom (and perhaps even before this as well).[23]

This limit of the human—its inability to birth forth life *de novo*— may not seem like much, as we excel at the control, manipulation, of life, as well as expediting its extinction. That being said, life in its entirety cannot be extinguished by the human, though life as we know it can undoubtedly die, including us. It is imperative to disentangle life in its entirety from the human in order to understand that the category of life will always *exceed* the human. In our age of ecological crises, reminding ourselves that the human is a contingency is much more politically useful than to frame our existence as expected.

Instead of declaring ourselves as the expected outcome of life, we must re-embed ourselves in its (billions year old) history. In doing so, we may be able to understand ecological questions in a new way, especially if, as Dipesh Chakrabarty has argued, the human *in*ability to comprehend geological timescales with human timescales makes it difficult for us to grow an

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[22] Historian of science John Farley attributes this phrase to William Harvey (1578-1657), who was a supporter of spontaneous generation. This phrase therefore was originally meant to *affirm* spontaneous generation. I, however, am appropriating this phrase and changing its meaning. By "egg," I mean thinking here with embryogenesis in an ontological register, and especially with Ruyer, who argues that the universe itself is a kind of cosmic "egg" in the process of its own embryogenesis. Ruyer has a distinct understanding of the relation between what we traditionally understand as nonliving and living. He considers the relation between embryogenesis and evolution with memory through an analysis of its relationship to themes or thematic activity. His concept of primary forms or absolute domains *cuts across* the sciences, and thereby results in a radical new understanding of the origin of life. Under this new metaphysical paradigm, the "historical origin of life no longer arises" (*Neofinalism*, 52). To say that all life is from an egg in a Ruyerian sense is to suggest that self-making properties we see in cellular life have their origins in the beginnings of the universe itself. There is a virtual fibrous thread of continuity for Ruyer that spans from the origins of the universe to all living forms.

[23] Ruyer, *The Genesis of Living Form*, 36.

ecopolitics.[24] The contingency of the human must be affirmed, as well as its existence being fundamentally dependent on relations.

Irigaray has formulated a concept of life that conceives of living *as* relation. Living must always be thought *in relation*; this is why Irigaray dissolves a logic of self-identity to posit a relation-identity. This particular idea of identity "cleaves" across distinctions of active/passive, form/matter, and nonliving/living. "The living," for Irigaray, "is that which continues to grow, to become."[25] This growth is never simply an increase of the same, but, at the same time, the new cannot be ushered in a way that would destroy the same. A living being continues to become by carefully and endlessly modulating itself. It invents new ways to live, but in a manner that does not exterminate its genealogy (because to do so would mean it would annihilate its own existence).

In addition to a relational-identity that marks life, Irigaray, like Ruyer, also theorizes the particular way life is self-making. This dissertation argues for a two-fold conception of matter. First, particular material (geological, geochemical far-from-equilibrium) conditions are necessary for life as a force to emerge. Second, as the last two chapters make clear, I argue for a materialism that is never simply just material, in that materialism must contain within it the incorporeality of sense that makes matter more than material. If the origins and subsequent evolution of life entails a continuity between physico-chemical forms and organic forms, this project asks what makes this form of continuity possible. I argue that this continuity entails a material as well as immaterial elaboration. If the beginnings of proto-cellular forms of life that lead to cellularity, what must 'emergence' consist in for this event to occur? This is the idea that the material cannot

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[24] Dipesh Chakrabarty, "The Climate of History: Four Theses," *Critical Inquiry* 35 (Winter 2009): 197–222.
[25] Irigaray, *Conversations*, 7.

frame itself, and is thus always in relation to form. This idea of an incorporeal directly connects to Irigaray's formulation of a philosophy of sexual difference entailing a sensible transcendental—a concept she creates that spotlights how form and matter, or mind and body "ceaselessly wed."[26] This intimate relation between matter and form that marks all of life is not a passive link—on the contrary, a tension always inheres in this relation, making it a generative relation that incites becoming.[27] Irigaray's formulation of a sensible transcendental makes her a major contributor to contemporary feminist materialisms. She calls for a rethinking of matter that emphasizes the centrality of the material conditions of emergence, while simultaneously thinking the relation between matter and form anew. It is this twofold orientation to matter and life that a feminist philosophy of life carries within it, and what makes it uniquely positioned to theorize not only the conditions of emergence, but also life's (virtually) endless transformations.

The emergence of cellular life from matter as an expected event reimagines the relation between these two terms in a non-binaristic formulation. Life is not an external outside that sometimes animates matter. Life and matter can be understood as tendencies rather than opposites, where the possibility of life is virtually latent within matter. Alongside this tendency, there is something about life that cannot be made in a lab: the specificities of its living form. Indeed, origins research excels at generating the chemical precursors of life, but cannot bring

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[26] Irigaray, *An Ethics of Sexual Difference*, 37.

[27] Pheng Cheah further elaborates on this point. He writes that Irigaray "is suspicious of philosophies that separate the ideal from the real and which regard the ideal as a simple beyond or outside from which to reshape the real. Her critique of patriarchal religion and the complicity of what, in shorthand, I'll call "idealist" philosophies with patriarchy is apposite here. For Irigaray, sexual difference is a sensible transcendental. It is an outside that is in the inside of the real and concretely so...For Irigaray, the possibility of the future inheres in that which gives the present, namely the interval of sexual difference" (Pheng Cheah, "The Future of Sexual Difference," 33.)

about living form.[28] This is something that marks all of life, including the human. On this, Irigaray writes:

> Through its natural belonging, human being has in itself the source of the motion which leads it to grow. Its physical matter is endowed with an energy which urges it to develop, and not in an undifferentiated way, but in accordance with forms which are its own. Human being has the potential of a plant that grows by itself without needing an impulse brought to it from the outside. Nature, contrary to a fabricated object, moves by itself towards its blossoming.[29]

She goes on to argue that "this by itself" does not mean that life cannot utilize exterior elements in its unfolding (akin to how metabolism brings in exterior components for its functioning). Human beings are an expression of this matter-energy that continues to differentiate. We share this feature that runs through all of life; but it is this exact intrinsic and fundamental property of life that we ourselves cannot manufacture.[30]

Perhaps the study of our origins should not make us feel expected so much so that we become complacent with the world as it is. The origins of life does not ensure the expectedness of the human, but understanding our origins, especially the conditions of our emergence, can generate a new way to live. In *To Be Born,* Irigaray suggests,

> Unveiling the mystery of our origin is probably the thing that most motivates our quests and plans. This question so much worries us that, perhaps, we have not yet begun to live, in ourselves and in the world. We would like to know from where we come, from what or from whom we exist, in order to dwell there and grow in continuation with that from what or from whom we are.[31]

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[28] To be fair, self-organizing chemical reactions, such as the famous Belousov-Zhabotinsky (BZ) reaction, are self-organizing reactions that can be generated in the laboratory. These reactions are often thought to be either: chemical analogues to life in a strong sense, or, at least serve as inspirations of how to understand life in a weaker sense. A reaction such as the BZ reaction does demonstrate the generation of order that rhythmically oscillates between different states, but cannot be conflated with the generation of living form.

[29] Irigaray, *To Be Born*, 13.

[30] Making cellular life from no pre-existing cellular parts is different from human reproduction, which is an extension and further complication of already existing (complex) human life rather than creating cellular life in its most primordial sense.

[31] Irigaray, *To Be Born*, v.

Our search for our origins motivates our search for how and where we were born, as well as our culture, religion, and language. But it also manifests "in what we project onto the most distant future but which, in reality, corresponds to the quest of the most indiscernible closeness."[32] Our origins not only direct us to our past, they also orient us to the future. A more robust relation to origins would not encourage the complacency of the human—it would not perpetuate the fiction that its existence was expected. It would instead remind the human that life will always precede and exceed its existence, and that because of this, it should cultivate new ways of acting and thinking that root it in a logic of *relation*. The conditions of emergence may abound, but that does not mean they all support and center the human.

The recent turn to life in feminist scholarship extends long-standing feminist critiques of Enlightenment humanistic and liberal discourses in that it continues the targeting of "Enlightenment Man" that has been ongoing for four decades, during which there has been rigorous attention to find "the fault lines in masculinity cultures" and the bodies, and ways of knowing, they ignore, denigrate, and exclude.[33] What is perhaps new in more recent feminist philosophies of life is the "a bold move beyond critique toward creation."[34] Here, the decentering of limiting enlightenment discourses operates less through the means of critique and instead "imagine and cultivate new ways to speak, think, and act."[35] This project theorizes new ways to think and act by reimagining the ontological relation between matter and life.

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[32] Irigaray, *To Be Born*, v.
[33] Ladelle McWhorter, "Foreword: Why Life Now," in *Feminist Philosophies of Life*, iii, citing *Genevieve Lloyd*, *The Man of Reason: "Male" and "Female" in Western Philosophy* (London: Routlege [1984] (2002)), Susan Griffin, *Woman and Nature: the Roaring Inside Her* (New York: Harper & Row, 1978), and Carolyn Merchant, *The Death of Nature*: *Women, Ecology, and The Scientific Revolution* (New York: Harper & Row, 1990).
[34] McWhorter, "Foreword: Why Life Now," iv.
[35] McWhorter, "Foreword: Why Life Now," iv.

Attention to questions of ontology are not as directly urgent for a feminist philosophy of life as more explicit, projects that concern the lives that are in immediate peril. Nonetheless, questions concerning the most abstract metaphysical and ontological aspects of life must be asked for feminist theory to flourish in its most robust form. As Hasana Sharp and Chloë Taylor remind us, to craft a feminist philosophy of life, "it is not enough to expose the tendency of discourses to normalize and exclude racialized, feminized, differently abled, and gender nonconforming people, although such a task remains central to feminist theory....It is also necessary to ask what life is. What are the conditions under which life on Earth is possible? To what extent do we share the struggles and needs of other living beings?"[36] The question of life, even in its most abstract form, is always a political question,[37] though the immediate weight of this question ranges from imminently pressing—as in the question of which forms of life are valued, are thought to matter, and to be grievable—to more a speculative politics concerning the nature of life as such and its relation to matter. Both are necessary for feminist politics.

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[36] Sharp and Taylor, "Introduction," *Feminist Philosophies of Life*, 1-2. It should be noted that they use feminist *philosophies* of life in order to address the plurality of knowledges that fall under this broad conceptual umbrella. This project is one thread among many in this plurality of feminist philosophies of life.

[37] Though I have not explicitly addressed this in my body chapters, to be clear, origins research is not free from explicit contemporary modes of biopolitical power and control. Like any scientific field of knowledge, it is not "apolitical." The discovery of hydrothermal vents in the late 1970s, the focus of my first chapter, was precipitated by the United States Navy heavily investing in explorations of the deep sea in order to monitor and control these ocean waters in the context of the Cold War (Naomi Oreskes, "A Context of Motivation: US Navy Oceanographic Research and the Discovery of Sea-Floor Hydrothermal Vents," *Social Studies of Science* 33, no. 5, (2003): 697-742). In its desire for neutrality, science often willingly divorces itself from its geopolitical context. In more contemporary terms, research focusing on hydrothermal vents that release methane (CH_4) are now also sites of interest for deep sea mining (Andrew Thuber, "Hydrothermal vents, methane seeps play an enormous role in marine life, global climate." May 27 2016. Accessed November 14, 2019). In addition, interest in an ancient RNA world, the focus of chapter three, coincides with scientific interest in how RNA can be utilized in medical and scientific practices of today. RNA's dynamic abilities give it a significant role in cellular life's beginnings as well as making it an object of financial and scientific interest.

This dissertation is a response to what Sharp and Taylor remind us. It argues that conceptually rethinking of life, and its conditions, are as crucial for our contemporary political moment as on the ground struggles. In alliance with contemporary struggles for life, feminist philosophies of life must make space for more abstract questions regarding life and its relation to matter and the Earth, because it is here that conceptual displacement of the human can generate a new onto-ethics—in other words, "an ethics of life lived in a world of difference."[38]

A feminist philosophy of life that investigates cellular emergence must rethink the relation between matter and life by submerging itself in the fluid milieu that all of life requires. It is here where the relation between form and matter, mind and body, the ideal and material can be reframed, and in doing so, generate a non binaristic relation between matter and life. Thinking through a fluid body can powerfully reimagine the dichotomies that too often dictate how we think and what we understand nature or the "real" real to be.[39] Rooting oneself in a womb—like thinking through the body—provides a novel way to understand the question of form as it relates to life, which is arguably one of central questions of biology and thus must be theorized in its emergence. As Irigaray reminds us, **"**if form were no longer extrapolatable from matter, if matter and form should engender one another endlessly, without a limit prescribed by the domination of the one—the One—over the other-wouldn't this perspective re-open another mode of

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[38] Elizabeth Grosz, "Irigaray, The Untimely, and The Constitution of An Onto-Ethics," *Australian Feminist Law Journal* 43, no. 1 (2017): 16.

[39] Here, I am thinking with Eleanor Kauffman, who argues that "thinking through the body" allows us to move beyond dualistic thinking, while simultaneously allowing us to fundamentally rethink the concept of mind just as much as we can the body. Drawing on Grosz's *Volatile Bodies*, for Kauffman, this orientation allows for the formulation of the incorporeal, a concept that becomes available to feminist theory through the rethinking of the body. See Eleanor Kauffman, "Toward a Feminist Philosophy of Mind," in *Deleuze and Feminist Theory*, ed. Ian Buchanan and Claire Colebrook (Edinburgh: Edinburgh University Press, 2000), 128.

exchange?"[40] This inseparable relation between form and matter would confound "both the force of binarism and the substance-origin that it supports and maintains."[41] Not only would it reshape the relation between and among (all) the sexes where the privileging of one subject over and above all others would cease to exist, and in the process, create the possibility for an ethical relation between sexed subjects to exist. It would also reimagine and reframe the human's relation with the concept of life by reminding it that it is one relation *among* many.

[40] Irigaray, "The Language of Man," 199.
[41] Irigaray, "The Language of Man," 199.

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Biography

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