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viral memory and the philosophy of morphogenesis

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> "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 inherently carries 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?

In this essay, 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 essay 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 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 *Creative Evolution* (1907), Henri 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.
>
> 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 unorganised 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 organised 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* utilised 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 revolutionised how we understand the reality of Nature, Raymond Ruyer is able to take up the question of the relation between organic memory and life in novel 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 theorise 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 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 paper thinks in the space that unfolds from the physicochemical and the organic to consider how viruses offer us the grounds to theorise how memory, reproduction, and instinct begin in the organic realm.

In origins of life research, the beginning of genetics is often rooted in a "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, the centrality of DNA is displaced in discussions regarding cellular emergence. 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. 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.

RNA world experimental researchers deploy either a 'top-down' or 'bottom-up' approach. The top-down 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 catalyse 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. Bottom-up research, by contrast, aims to *simulate* the ancient RNA world by creating 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*. 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. Though a bottom-up approach does not succeed in making genuine living forms, virological research brings us much closer to the possibility of an ancient RNA world. Viruses and viral-like entities known as viroids are considered by some scientists to be connected to the RNA world. Viroids help us conceptualise the RNA world because they are, to use Ruyer's terminology, "primary forms" that are self-making, and thus possibly explain how living form of RNA itself came into being.

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, some researchers suggest that the beginning of RNA was viral in nature. My goal in exploring the possible viral origins of genetics (in a putative RNA World) has been 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, 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 paper 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 crystallised by researchers, 3) can spontaneously re-assemble after they are chemically denatured or disassembled, and 4) can be generated by researchers *de novo* 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 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 from the origins of genetics billions of years ago (which are impossible to access)—nonetheless provide the raw materials to understand what a feminist philosophy of life would entail.

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] A study published in *Nature* in the year 2000 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 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 have been increasing those attuned to the reality of the effects of viral evolution. One article summarises this point as follows: "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 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 here is to not to focus on these viral evolutionary effects but rather to explore the particular ontological nature of viruses as primary forms. In other words, while still acknowledging the (often evolutionarily 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. This Ruyerian designation is much more generative to think with than debates about whether viruses are 'fully alive.'[13]

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 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 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 essay addresses how the thematic development of primary form moves from the molecular to the organic, by focusing on how viruses have theoretically and scientifically understood to be key agents in this shift.

CONTINUITY AND THEMATISM

In his 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 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.

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

VIRUSES AS CHEMICALS

If viruses can be theorised 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 *crystallised*.[24] This was accomplished in the laboratory using large amounts of TMV infected plant leaves. TMV's ability to be crystallised 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 crystallisation of cellular life is impossible, that viruses could be crystallised signaled the radical difference between these two modes of life. Wendell Stanley, the biochemist and virologist who accomplished the crystallisation 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?"[25]

Around the mid-twentieth century, viruses were understood as chemicals due to their crystallisable 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.[26]

That viruses can be crystallised (when aggregated in large quantities) demonstrates that they are *chemical* in nature at least in one sense of the term. This ability to be crystallised, however, does 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 crystallisable 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."[27] 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 crystallisable 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 crystallised. 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%.[28]

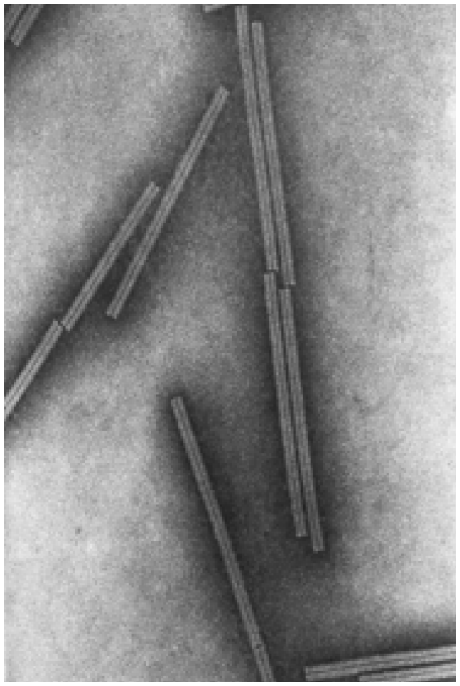

Figure 1: "Electron Micrograph of Rod-Shaped Particles of TMV magnified 300,000 diameter"[29]

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-organisational 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."[30] That Tobacco-mosaic virus self-organises 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.

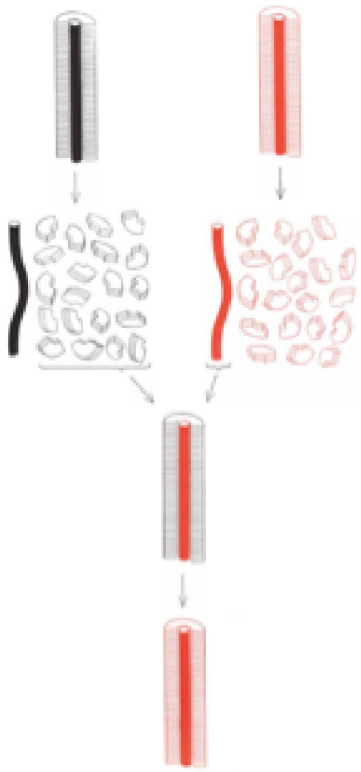

Figure 2: Creation of viral hybrid from two virus strains, and reproduction of created hybrid resulting in non-hybrid offspring (Fraenkel-Conrat, 1957)

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.[31] 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 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).[32]

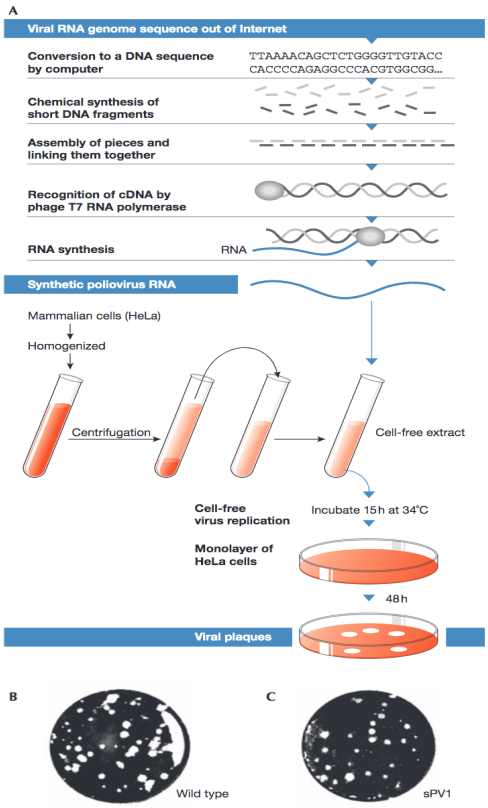

Figure 3: Synthesis of a poliovirus in the absence of natural template[33]

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."[34] 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.[35]

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. That being said, this experiment does indeed give new force to the idea that viruses are chemicals with life cycles.

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 an 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 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."[36] Ruyer 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.[37]

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 revolutionised if one then contemplates how matter itself is dynamised 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, 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.

Ruyer is a rich resource to understand the genesis of living forms because of the ample attention he gives to theorising 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.[38]

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 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.[39]

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 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.

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.[40]

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 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.'"[41] 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.[42]

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."[43] 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.[44] 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 emphasises change) with Mendelian genetics (which emphasises genetic stability).[45] For Neo-Darwinists, "the morphogenesis of a species is the accumulation of fortuitous mutations."[46] Indeed, viral reproduction *seems* to affirm Neo-Darwinism because here we are dealing with reproduction via division where "all structural mutation is naturally transmitted."[47] "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."[48]

While one way to understand viruses as chemicals is through their ability to be crystallised, another understanding becomes possible if we consider the relation between chemicals and temporalised 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 a consideration of 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 miniaturised 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*."[49] In other words, the atom itself is a structuring activity in touch with its form. An example of this is how carbon, which has the capability to form four bonds, "is not a structure but a *structuring activity*."[50] 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*."[51] "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 temporalised 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.[52]

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.'"[53] This is to say that the structure of matter cannot be separated from its temporal

behavior.[54] 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."[55] This rendering of matter challenges the idea of time as an empty dimension or "empty and foreign frame."[56] 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."[57] 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 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.[58]

Physical beings are not static precursors. They enjoy a structuring activity that coincides with temporality, and thus, for Ruyer, also with memory.[59] 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.[60]

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 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.[61]

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 the relation between viruses and invention is, 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 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 much more likely to be negative than positive.

In this consists 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."[62] 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 understanding "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.[63] 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?[64]

Building on the Neo-Darwinian refusal to understand the morphogenesis of species as a thematic invention, mutation in this context 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 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.

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NOTES

1. August Weismann, The Germ-Plasm: A Theory of Heredity. Trans. W. Newton Parker. New York: Charles Scribner's Sons, 1898, xi.
2. This substance is "immortal" for Weismann only to the extent that there is reproduction.
3. Henri Bergson, Creative Evolution. Trans. Arthur Mitchell. New York: Random House, 1944, 23-4.
4. Bergson, Creative Evolution, 25.
5. Bergson, Creative Evolution, 19.
6. Ruyer is mostly critical of Bergson in the few places in Neofinalism (1952) and The Genesis of Living Forms (1958) 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 critics of his day—Ruyer diagnoses Bergson's problematic binarisation 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." "Bergson and the Ammophila Sphex." Trans Tano S. Posteraro. In "Instinct, Consciousness, Life: Ruyer Contra Bergson." Angelaki 24:5 (October 2019, 134).
7. Ruyer, Neofinalism. Trans. Alyosha Edlebi. Minneapolis: University of Minnesota Press, 2016, 154.
8. Jane Bennett can be credited with popularising these experiments in Vibrant Matter: A Political Ecology of Things. Durham: Duke University Press, 2010.
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 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).
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 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. Trans. Jon Roffe and Nicholas B. de Weydenthal. London: Rowman & Littlefield, 2020, 38-9.
14. Mark B. N. Hansen, "Introduction: Form and Phenomenon in Raymond Ruyer's Philosophy" in Ruyer, Neofinalism, ix.
15. Ruyer, The Genesis of Living Forms, 25.
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.
18. Elizabeth Grosz, The Incorporeal: Ontology, Ethics, and the Limits of Materialism. New York: Columbia University Press, 2017, 215.
19. Ruyer, The Genesis of Living Forms, 30.
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.
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 piece.
25. Wendell M. Stanley, "The isolation and properties of crystalline tobacco mosaic virus" in Nobel Lectures: Chemistry, 1942-1962. Singapore: World Scientific, 1999, 140.
26. Ruyer, The Genesis of Living Forms, 40, original emphasis.
27. Ruyer, The Genesis of Living Forms, 29.
28. Heinz Fraenkel-Conrat, "Rebuilding a Virus," Scientific American 194:6 (June 1956, 42).
29. P. Jonathan, G. Butler, and Aaron Klug, "The Assembly of a Virus," Scientific American 239:5 (November 1978, 63).
30. Jonathan, Butler, and Klug, "The Assembly of a Virus," 62.
31. 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).
32. 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, i.e., a "native" virus).
33. Eckard Wimmer, "The test-tube synthesis of a chemical called poliovirus: The simple synthesis of a virus has far-reaching societal implications." EMBO Reports 7 (2006, S3-S9).
34. Cello, Paul, and Wimmer, "Chemical synthesis of poliovirus cDNA," 1016.
35. Cello, Paul, and Wimmer, "Chemical synthesis of poliovirus cDNA," 1018.
36. Ruyer, Neofinalism, 30.
37. Ruyer, The Genesis of Living Forms, 31, emphasis added.
38. Ruyer, The Genesis of Living Forms, 42-3.
39. Ruyer, The Genesis of Living Forms, 43.
40. Raymond Ruyer, The Genesis of Living Forms, 38.
41. Raymond Ruyer, "The Mystery of Reproduction and the Limits of Automatism." Diogenes 12 (1964, 54).
42. Ruyer, "The Mystery of Reproduction," 54-5, emphasis added.
43. Ruyer, "The Mystery of Reproduction," 55.
44. Ruyer, The Genesis of Living Forms, 22.
45. 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." See 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 idea that evolution occurs through a slow "gradualism," arguing that there is no evidence of this "slow gradualism" in the fossil record.
46. Ruyer, The Genesis of Living Forms, 21.
47. Ruyer, The Genesis of Living Forms, 22.
48. Ruyer, The Genesis of Living Forms, 25.
49. Ruyer, The Genesis of Living Form, 35.
50. Ruyer, The Genesis of Living Form, 36.
51. Ruyer, The Genesis of Living Form, 36.
52. Ruyer, The Genesis of Living Forms, 38, emphasis added.
53. Ruyer, Neofinalism, 148, citing Louis de Broglie, Continu et discontinu en physique moderne. Paris: Albin Michel, 1951, 66; 74.
54. Ruyer 148, citing Robin George Collingwood, The Idea of Nature. Oxford: Clarendon Press, 1945, 146.
55. Ruyer, Neofinalism, 149.
56. Ruyer, Neofinalism, 149

57. Ruyer, Neofinalism, 149
58. Ruyer, Neofinalism, 149, emphasis added.
59. Ruyer, Neofinalism, 149.
60. Ruyer's conception of memory differs from memory is automatically preserved for Bergson. See Ruyer, Neofinalism, 128: "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."
61. Ruyer, Neofinalism, 132.
62. Ruyer, The Genesis of Living Forms, 21.
63. Ruyer, The Genesis of Living Forms, 21.
64. Ruyer, The Genesis of Living Forms, 22, original emphasis.