

IN SEARCH OF THE CONCEPT OF LIFE:  
LESSONS FROM ARISTOTLE, KANT, AND HEGEL IN INTERFACE WITH MODERN  
SCIENCE

by

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(Under the Direction of Richard Dien Winfield)

ABSTRACT

This dissertation addresses the concept of life and how the philosophical understanding of life underlies scientific investigation of biological phenomena. The first part critically examines Aristotle's attempt to distinguish living from non-living beings in virtue of the apparent self-moving "ensouled" character of organisms. Aristotle's conception of life is shown to be marred by incompatible features of his conception of causality and motion. The dissertation next turns to Kant's understanding of life to examine whether Kant's appeal to a conception of internal teleology is better able to capture the essence of life. Kant's mechanistic conception of nature, however, is shown to render teleology unknowable by our understanding. The dissertation next turns to Hegel to find a remedy to the problems Kant leaves unresolved. Hegel's understanding of chemistry is shown to provide objective knowledge about the features of life that Kant thinks but cannot know. Although Hegel's understanding of life is limited by the scientific knowledge of his time, Hegel's basic conception of the chemistry of living organisms proves to be compatible with some of the most current scientific theories of life, such as

those that appeal to autocatalytic and autopoietic reactions. In addition, Hegel's discussion of the geological environment in which life can emerge and sustain itself anticipates some aspects of the Gaia Hypothesis, according to which the earth can be considered a living system. The dissertation concludes by showing how Hegel's account of life and its biosphere provides strong arguments for countering the Gaia Hypothesis that the Earth is alive.

Index Words: Aristotle, Kant, Hegel, life, biology, metabolism, reproduction, organism, evolution, Gaia, biosphere

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## INTRODUCTION

Contemporary sciences have provided us with detailed empirical understanding of living beings, the structure of their components, the mechanism of their function and how they interact with the environment. Nonetheless, only a philosophical understanding can establish that these scientific studies actually reveal what is essential to life. Prevailing views of life have relied upon a certain list of characteristics that are presupposed to be exclusively possessed by living beings. The content of the list is itself a matter of controversy that no empirical investigation can resolve.

To overcome this controversy, this dissertation turns to examine critically the philosophical theories of life developed by Aristotle, Kant, and Hegel. In exploring their philosophical contributions, we will attempt to clarify how life should be understood. In doing so, we will address two further questions. First, how do these philosophical conceptions and contemporary scientific theories of life bear upon one another? Second, how can we expand our understanding of living beings to extraterrestrial worlds? What are the reliable signs of living beings elsewhere in the universe, what are the types of astrophysical bodies on which life can arise and be sustained, and do such bodies comprise living systems that transcend individual organisms?

## CHAPTER ONE

### ON ARISTOTLE'S CONCEPT OF LIFE

Aristotle's concept of life has three aspects. The first is that of life as a moving whole, which contains an internal principle of motion within itself. The second aspect involves how in a living organism, three out of four types of causes are combined: the formal cause is a final cause, and it is also the efficient cause (the moving cause); Understanding this combination can facilitate the understanding of life as a moving whole. The final aspect is illustrated by Aristotle's concept of the soul, which is a particular kind of form with an active power of life within it. From these three aspects, Aristotle identifies living organisms in the world; however, on the one hand, without the soul, he is unable to isolate animate from inanimate natural things; on the other hand, having the soul seems to be a good solution, yet the concept of the soul is problematic in many aspects. Aristotle applies a single teleology to the whole natural world. As a result, it becomes impossible for him to draw a clear boundary between an organic and inorganic world. Nonetheless, it is worth exploring the three aspects of Aristotle's account of life which each contribute to our understanding of what makes something alive.

## 1.1 The Concept of Life From the Perspective of Motion

At the beginning of *Physics*, Aristotle states that all our inquiries must start with what is the most obvious to us, i.e. motion. Therefore, when we study Aristotle's concept of life, it is reasonable to start with his discussions of the particular way living beings move.

In *Physics* Book II, Aristotle defines motion (*kinesis*)<sup>1</sup> as “the actuality of potential, qua potential,” which suggests that all kinds of changes are motion. Aristotle points to four distinct senses of motion: alteration (qualitative change), the change in position, generation or corruption, and increase in magnitude (*De Anima*, 406a12). Locomotion, which involves change of place, is just one kind of motion. In locomotion, the surroundings of an object actualize that object's potential for being moved from one place to another. This process itself is only possible if in the object's immediate surroundings there is something to trigger and maintain this process. This holds true for all motions.<sup>2</sup>

To further clarify Aristotle's concept of motion, we can consider the process of setting a piece of paper on fire. A piece of paper has the potential to be ignited; a lit match touching paper can set it on fire. Then, the piece of paper is also in motion because its potential for burning is being actualized. According to this theory, the growth and self-maintenance of plants are also motions. First, seeds actualize their potentiality

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<sup>1</sup> Also in *Physics* Book 3.1 (200b13). The paragraph referencing to Aristotle in this dissertation are those used in *Complete Works of Aristotle*, Volume 1: The Revised Oxford Translation, listed in my bibliography. For the rest of this dissertation, I will only use the paragraph referencing.

<sup>2</sup> When Aristotle defines life as “Self-motion”, he should be thinking of the change in quality, such as growth and decay. This is the kind of change common for all living beings.

for becoming mature plants through sprouting and growth. This process of actualization is dictated and led by the nature of the seed. Once seeds reach their mature status, they then actualize their potential of maintaining themselves by interacting with their surroundings. Both of these actualization processes are only made possible by their surroundings. Seeds in a hostile environment will never sprout. It is like the paper and match example: the potential of being flammable will never be actualized without the match being in the same setting. This process itself is only possible if there is something that can trigger and maintain the process in the immediate surroundings of the object. Living beings, both animals and plants, relate to their environment through nutritive motions: both require a certain kind of nutrition-aimed interaction with their environment to maintain their particular existences. In addition, both have a consistent circulation in each individual to maintain its ability to actively engage with its environment. However, animals have two other motions that plants do not: locomotion (as a whole) and sensation (desire).<sup>3</sup> Animals have feelings and desires. It is clear that motion in Aristotle's sense is only possible under at least two conditions – a potential waiting to be actualized, and something in its approximate surroundings which can actualize this particular potential. This is true for the locomotions and desires in animals; and it is equally true for the spontaneous motions which are shared by animals and plants. Those motions cannot be found in inorganic things. Aristotle claims that every motion

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<sup>3</sup> The discussion of life is really about how plants are different from non-living beings. I will involve discussions of nutritive motion in animals as well since motions in animals are most easily observed.

requires a mover, and the mover must be in physical contact with the moved.<sup>4</sup> We must keep this concept of motion in mind, as we further explore Aristotle's discussion of life.

Aristotle identifies living things by their particular type of motion. This study focuses on the difference between organic and inorganic entities, so motion in this discussion is not restricted to the motion of animals. To identify living beings, we should focus on the motion which is exclusively possessed by all living beings, plants, and animals. Keeping this in mind, we focus on those motions that keep plants and animals alive. They are the nutritive motions in Aristotle's discussion.<sup>5</sup> Nonetheless, most of our discussion considers motion in animals. The reason is that Aristotle uses the study of motion in animals to develop his own detailed theory of motion. His *De Motu Animalium* uses animals as an example to demonstrate his understanding of motion and how the soul works in moving living beings. Therefore, it is reasonable to use animal motion to investigate Aristotle's understanding of the particular motion of living beings, but it is important to be careful not to use animals to represent the living beings in general.<sup>6</sup>

Aristotle first notes that animals have a spontaneous locomotion which is not dictated by their material constituents. Animals still have the same locomotion that other non-living beings do because of the nature of the elements they are built with; animals are made of flesh and blood. According to Aristotle, these elements should go downwards once they are set free. Most animals stay on the ground all the time. If they

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<sup>4</sup> The unmoved mover is the only thing that can move others without any physical contact. Since the unmoved mover is a pure actuality, and our discussion of living beings involves material existences, the discussion of the unmoved mover lies outside the investigation of living things.

<sup>5</sup> Similar to metabolism in a contemporary context.

<sup>6</sup> In chapter 10 of *De Motu Animalium*

jump, they fall back to the ground. Although birds can fly, when they stay still they fall towards the ground because of their material. However, animals have a completely different motion of their own. Without any apparent mover, animals can jump, leap, howl, fly etc..

Given Aristotle's concept of motion, animals' spontaneous locomotion requires heterogeneous parts. The whole animal can be divided into an active and many passive parts to explain the behavior of the whole. The mover inside each animal triggers the motion of the whole, although where and how the mover exists inside animals is not clear to us – all material parts of the animal can move at the same time without a fixed temporal order, so we cannot easily identify the material existence of the first mover in animals (or plants). To understand how living beings seem able to move themselves, Aristotle needs to discuss whether there is an unmoved mover in them: what moves them? Is a mover in them? Aristotle invokes nutritive power to answer these questions to a certain extent, then uses the soul to explain the essential of those motions in his *De Anima* and *De Motu Animalium*.

This recourse to active and passive counterparts appears in many different areas in Aristotle's philosophy, e.g., his arguments about teaching and the taught, and about ruling and the ruled. In all these arguments, the active and passive roles must be performed by different objects to enable them to function. Self-moving things do not make sense if they are indivisible wholes since the mover must be separate from the moved whole, yet in this case it is part of the whole. Consequently, for something to be able to move itself, it must have separate active and passive parts in order to initiate motion within the moving object. Although animals can be divided into parts, those parts

cannot be distinguished simply as the mover and the moved. Different parts of animals have the potential to perform various functions. The actualizations of those functions are motions. Aristotle recognizes that the parts function interconnectedly and interdependently as cohesive unity. For example, for an animal, the heart does not work without the lungs, and *vice versa*. This tells us that these two parts must be moved at the same time: it is impossible to move one of them before the other. In animals, such reciprocal association involves most of their parts; where for plants, such association still exists, but not as closely. For example, a leaf without roots or roots without a leaf could function by themselves to grow out a whole plant. The association still exists because each part of the plant still needs to work mutually with others to sustain its own function. In order for some of the animal parts to be moved by another part of the animal, the mover must be a part of the animal which can function independently from the rest of the parts. For example, the heart cannot be the first mover, because it cannot function without at least some of the other organs being moved. Is there any part of a living being that can work independently from the rest of the body that can be the first mover of the animal?

Aristotle notices that there is a mutual dependence among certain organs of an animal.<sup>7</sup> It is clear that different parts of animals depend on other parts of the body on a different level. However, this reciprocity, as described in the example of the heart and the lung, holds throughout the whole organism. Humans can survive without hands, arms, or even some internal organs such as an appendix, but losing the heart causes loss of life. From this observation, we know that the functioning of some parts of the

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<sup>7</sup> This feature also applies to plant life.

animal, such as hands or limbs, is caused by the functioning of the whole but doesn't cause the functioning of other organs. Those parts whose functioning heavily depends upon the other parts, such as the heart, cannot be the first mover of the whole body because the functioning of the heart presupposes the functioning of many other parts of the body. To be the first mover, the part must be able to function without any other part of the whole body. It is hard to identify a possible first mover in animals, yet from observation it seems easy to find one in plants, because the interdependency between parts of a plant is not as close as that between parts of animals. A whole plant can grow out of a single leaf with appropriate conditions. However, regardless of this relative independence, leaves cannot be the first mover because the existence of leaves presupposes the existence of a whole plant – without the existence of such a plant there would not be any leaves, not to mention the active power of growing a whole plant out of one of its parts. Because of the interdependency among parts of any living thing, it is impossible for any parts of the living whole to be the first mover.

It is impossible to label parts as merely movers or moved. For example, the heart moves the blood, but meanwhile the circulation of the blood also ensures the continuous motion of the heart. Therefore, we cannot simply label them as a mover and a moved. The animal as a whole is not moved by any one of its material parts.

Therefore, either animals are moved by one of its immaterial components or it is moved by something outside it as a whole.<sup>8</sup> Yet even if a living being is moved by something outside it, it is moved in a different way from how an inorganic being is moved. On the one hand, the parts of an organic being have to be moved at the same time because

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<sup>8</sup> The situation is the same for plants as well as animals because those motions are shared by both of them.

they are in a reciprocal relationship – it is impossible to move one part without moving the rest of the whole.<sup>9</sup> On the other hand, this characterizing motion of organic beings is not mechanical displacement, but the reciprocal functioning of the organs. The potential they actualize is not simply mechanical displacement – they each have their particular purposiveness to fulfill.

Motion requires an agent to actualize its potential. In Aristotle's discussion, motion is not restricted to locomotion. An object's locomotion actualizes its potential to move when a mover is present to make it happen. However, actualizing a potential without locomotion is also considered a motion in Aristotle's discussion. So one object can be moved by a mover in the sense that a function is started by the mover. Still, that animals appear to move without any mover seems baffling.

In addition Aristotle suggests that an impact and its effect cannot be simultaneous. There should then be a temporal interval between the motion of different parts of animals. However, we cannot find an animal part which moves before other parts are moved. Aristotle's understanding of causation eliminates the possibility of mutual causation, because reciprocal causation requires the cause and effect to happen at the same time. In the case of the locomotion of animals, the mover is moved by what the mover is moving at the same time, and the temporal difference cannot exist.

Aristotle still distinguishes living things from nonliving things in that living beings have a particular kind of motion which appears to be self-motion. But it is impossible for him to have such motions originate from the material composition of the living being.

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<sup>9</sup> Physical motions of the body parts can happen independently: the left hand can be moved without moving the right hand. However, the functioning of the organs cannot happen without each operating in unity with the others. This is what makes organic beings different from inorganic beings.

Facing these issues, Aristotle tries to look outside living things for the mover and suggests that nutrients could be the mover of living beings.

Aristotle investigates nourishment to explain the spontaneity of life. Nourishment is a particular kind of connection that organisms have with their immediate environment; it is a particular kind of motion, i.e., assimilation. In this interaction, the living being takes in something from its surroundings and transforms it into a part of its own self by giving it an active form. Aristotle here argues that even though animals appear to move themselves, their motion is not strictly initiated by themselves – to a certain extent, their motions are caused by the outside environment. This situation is the same for plants. Although the interdependency between parts of plants is not as close as that between parts of animals, their existence presupposes the existence of the whole. Roots extend to absorb nutrition from their environments and leaves grow out to better assimilate sunlight from the environment. Similarly, seeds only germinate when an appropriate environment is provided. In general, the organism moves itself as a result of stimulation by its environment. Aristotle thinks this answers the question of how the organic process is activated initially.

Can the environment, according to Aristotle's theory, be a legitimate mover which is responsible for the special kind of motion we see in living beings? It is questionable whether nourishment is a purely external causation for a living organism. At first sight, the environment's moving a living thing is similar to paper being lit with a match. Both when a match lights a piece of paper, and an animal obtains nutrition from its surroundings, start when the two factors are near each other. One potential in paper is being actualized — being burned — while the potential of an animal is being actualized

— nutrition as nature dictates. The paper burns and the animal assimilates the nutritious object. The object providing nutrition might appear to be the mover of the animal in the same way as the fire is the mover of the paper.

The analogy becomes suspect if we focus on the difference between these two processes. The fire preserves its form while transforming the paper into something which is no longer paper. In comparison, the organism has an active power to transform the nutritious objects into a part of itself — by giving the object its own form; the organism takes the object into itself. Consider the differences between a stone and a plant in a river. Both might be moved by the force of the flowing water; they both might be changed by certain chemical interactions with the chemicals in the river. However, it is obvious that there is one interaction which is only possible for living plants, to engage in metabolic interaction with the river, through which water will be sucked in and become an active part of the plant. The water will participate in the organic process within the plant by contributing to its growth and sustenance. This kind of interaction can never happen in a stone or in other non-living things. Nourishment involves something more than being passively pulled or merely combusted; it is distinct from such types of interaction between the environment and inorganic beings. This distinction is actively rooted in the nature of the living organism. Living organisms have active ongoing self-renewing processes which make them distinct from those systems which can be explained within the scope of chemical and mechanical processes. This difference also answers the famous question as to how the animal taking in nutrition is different from a sponge taking in water. It is crucial how the form of the two factors changes through their interaction.

Two aspects of this discussion require more attention. One concerns the fact that the potential of the living animal is for preserving itself. It is worth asking how this potential is different from the potential non-living things possess, e.g., the paper's potential to be on fire. The other aspect is about the active power the animal has to give its own form to the nutritious objects of its nutrition.

Up to this stage, we have moved from what is most observable to us, i.e., the living things as apparently self-moving wholes, to the essential aspects which distinguish the living from the non-living as beings that have active interactions with their surroundings. Aristotle successfully recognizes and describes the two features which are unique for living things. In order to gain a deeper understanding of the changes that Aristotle identifies living things, we need to turn to Aristotle's discussion of the four causes and how they apply to life.

## 1.2 The Concept of Life from the Perspective of Self-causation

In Aristotle's inquiry into nature, it is always essential to understand causation. In the *Physics*, Aristotle states: "we think we do not have knowledge of a thing until we have understood its why, that is to say, its cause" (*Physics*. 194 b 17–20).

Aristotle's basic thoughts about causation are discussed in *Physics* II 3 and *Metaphysics* V2. For Aristotle, there are four distinct kinds of cause: material, formal, efficient, and final cause. These four causes are irreducible. It is clear that the Aristotelian causes are different from the Humean causes we are familiar with in the modern world. In the Humean concept, events are the causes and effects, whereas, in the Aristotelian system, it is substances that have causes. In the discussion concerning

animals, the two systems will answer the same question, i.e., “what causes a frog to jump,” from two different aspects. David Hume would search for a particular event which causes a particular jump: the jumping is an event which is caused by a preceding event; whereas Aristotle would tackle this question by considering what it means to be a frog — being able to jump under certain conditions is one feature of being a frog.<sup>10</sup> It does not make sense in Humean causation to ask what causes a table, because a table is not an event but an object. The action of making a table is an event, which is caused by another event that happened at an earlier time, and later causes other events. In contrast, in the Aristotelian system, “what causes a table” should be answered in terms of four causations.

1. Material cause: A table consists of wood.
2. Formal cause: Having a supported flat top is what it is to be a table.
3. Efficient cause: A carpenter, or a craftsman, is who makes a table.
4. Final cause: A table is for eating on.

The material cause and the formal cause explain the table’s matter and qualities, and the efficient cause and the final cause concern why it comes to be. Aristotle discusses the final cause in natural objects, in comparison with the final cause in artificial products, in *Physics*. This comparison is his first step in distinguishing living things from inorganic ones in a causal investigation:

It is strange for people to think there is no end unless they see an agent initiating the motion by deliberation. Even crafts do not deliberate. Moreover, if the shipbuilding craft were in the wood, it would produce a ship in the same way that

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<sup>10</sup> It is not very different from the early example: a part of being a paper is to be on fire when a lighted match ignites it.

nature would. And if what something is for (i.e., a final cause) is present in craft, it is also present in nature. This is clearest when a doctor applies medical treatment to himself—that is what nature is like. (*Phys.* II.8, 199b2)

It is clear that for Aristotle, the final cause does not exist as an intelligible end in someone's mind – in certain cases, actualizing the form of the thing is the final cause. Yet, this form must be a predetermined progression. The actualization of the form of a table, an example of a passive form, does not have a final cause in the table itself. The final cause is in the craftsman's mind. In contrast, to be a human, for example, is to follow a certain developmental path which defines what it is to be a human being. This path includes being able to walk at a certain age, being ready to reproduce at a certain age and so on. So the final cause of a human being is within itself. The formal cause of a human being is also within itself. To be a human being is to actively produce oneself from within, according to a certain form, to follow the developmental path of human beings. The formal cause and the final cause coincide, within themselves, in natural objects.

Aristotle uses house-building to explain the difference between natural self-motion and other motions, i.e., those motions that involve a separate mover and moved object. A house is built from unorganized and antecedently given distinct materials (*Phys.* 188b 17-18). A builder with the form of a house in mind can build a house out of these materials. In this house-building process, there is a change in the form of the materials and not a change in the house-builder (*Phys.* 202a 12-21). The builder, who is the agent of the building process, is separated from the bearer of the change, the raw materials. The final cause of the building process is for the owner to have a house, the

formal cause is the form of building in the builder's mind. The efficient causality is the actions of the builder and all the tools he uses. Is the house-building process essentially different from the natural changes mentioned in the previous paragraph? It is possible to modify the example to show that the final cause of the building process is to rent the house out to finish the building. In this case, the change itself seems to be the final cause of the process. However, this change is not the same as natural change. On the one hand, in this new process, the form that is being actualized is not the house, but the way in which the building plan is organized – building a house to finance the house-building process. The final cause of this is not to finish building the house – it must consider someone's profit. On the other hand, even if we focus on the house that is being built, it is clear that the form of the house is imposed by the builder who is not a part of the house. The change in natural objects and crafts (man-made products) is essentially different.

According to Aristotle, all natural objects are generated, but not made, because their form is not imposed by an artificer, who consciously has their form in mind and imposes them. Aristotle clarifies that the final cause in nature is the form:

Nature is of two sorts, nature as matter and nature as form, and the form is the end, and since everything else is for the end, the form must be what things are for.

*(Phys.ii, 199a30)*

Consequently, the form is more than making the object the way it is at each particular moment: the form also dictates and leads the developmental path a natural object has to go through. Going through this particular path is definitive of what the object is in and of itself. Being a human baby entails the need to follow the developmental path

prescribed by the form and the growth of a human, which is to be a mature and rational person.

M. B. Foster clarifies the differences between natural objects and artificial products within the Aristotelian system in his article “Christian Theology and Modern Science of Nature (I)”,<sup>11</sup> He points out that natural objects are generated by generators, whereas artificial products, or crafts in his term, are made by makers. Foster points out that an artificer consciously has the form of the artifact in mind before the production. A carpenter, for example, has a form of a table in his mind before making a table. The form he puts into the material is different from his own form, i.e. the form of human beings. In contrast, before a human birth, it is not necessary (indeed it is impossible) for the parents to have in mind the form of the thing to be generated. A parent passes its own form to the product, without consciously being aware of the form. One feature of this form is the ability to pass its own form down to the generated individuals by reproduction. For an individual animal, or a plant, the formal cause would include its particular anatomy, organization and an innate developmental path. The final cause of it is what it is meant to do, such as survival, reproduction. This is the same as the formal cause of the plant or animal. In other words, a final cause and a formal cause coincide in natural objects: the form of natural things includes the capabilities and potentialities (and even how they should actualize the potentialities), which defines its purpose, the final cause. The formal cause of organic beings inherently dictates a purpose (survival and reproduction).

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<sup>11</sup> Foster 1935

In addition to this, the efficient cause also coincides with the final and formal cause. Efficient cause is about how a change is impelled. The efficient cause of an inorganic being, say a desk, is the carpenter who made it, the tools he used, and the processes he undertook to make the desk. Those are factors that make the desk come to be. A desk does not have inherent changes that it follows by itself. Living beings have a particular developmental pathway that they have to follow consistently, such as growth and aging. Therefore, the efficient cause for inorganic beings only concerns “coming to be”. Indeed, a desk will likely be worn out after a period of time; however, this change is not inherent in its being a desk – a carefully preserved desk may last for centuries until external factors destroy it, yet a living being always grows or ages no matter how it is preserved. Living beings follow their particular developmental path as they stay being themselves – this efficient causality is guaranteed in their formal cause. Being a tree, for example, is to follow the developmental pathway to which the form of tree is dedicated. For Aristotle, the efficient causality of a living being concerns both its innate changing path and its coming-to-be. As Foster makes clear, the particular way in which each living being comes to be makes it essentially different from inorganic beings: living beings are generated by parents, whereas inorganic beings are made by craftsmen. Living beings get their particular form and end from the particular way they are generated and changed. The particular form they take also gives living beings their own final cause. The form living beings manifest is not a static form. To be a desk is to have a particular form, yet to be a living thing, such as a tree, requires the tree to constantly maintain itself through a particular developmental path.

This three-in-one coincidence is also clear when we consider each organ. To take the heart as an example, the final cause is its special role in the circulation system. This role is dictated by the active form it possesses – the way a heart functions to fulfill its role in the circulation system. The particular way the heart came to be and developed, i.e. coming into being as a part of a functioning circulation system and growing with it, is the very purpose its form requires it to pursue.

Having these features in mind, we can question Aristotle's analogy between a self-curing doctor and animate beings. In Aristotle's view, the sick doctor consciously has the form of healthy humans in mind, and by treating himself, he seeks to impose this healthy form on himself. He causes his own health—his own actions make himself develop along the path he is supposed to follow because of his nature. Aristotle uses this example to explain how in nature the formal cause and final cause coincide. This is not quite an appropriate example for the model Aristotle has in mind. The key difference is that the activity of curing is not itself a part of the product of that particular activity. Indeed, a doctor who has cured herself is likely to continue with her doctor's career to cure other patients and herself as needed. However, restoring/actualizing the healing power was not the purpose of the self-curing process - the purpose is to have a well functioning human body. For a living being, the purpose of the self-aiming functions is to maintain the very functions themselves. Curing is not the final cause in this process.

In addition, the curing processes cease once the health is restored – a healthy doctor does not need to be cured anymore. The curing process stops, but the purpose of this process, the healthy person, continues to exist. To be an authentic analogy to living beings, the curing-processes has to be the very way the healthy person exists – to

live should be to constantly cure oneself. The health of the individual doctor does not include the activity of medical intervention. For the analogy to be valid, the curing processes need to continue as long as the doctor exists. The processes in living beings preserve themselves – they produce the situation in which they sustain themselves.

The self-curing doctor does cause his own health and as a consequence of being healthy, the doctor can continue to cure himself when necessary. The end of his action is to reestablish the health that illness has undermined. Aristotle attempts to use this analogy to explain living beings undergo a self-renewing process to perpetuate themselves. However, for living beings, the self-renewing process is what they are producing. In comparison, the self-curing doctor's knowledge and action of curing are not produced by the action of curing. It is true that without being healthy, the doctor would not be able to perform this action; however, being healthy does not involve curative ability and curative action. The activity which produces healthy organisms is not a part of the activity of the healthy organism. Healthy organisms are not produced by the self-curing activity — they are generated by their "parents".

There is no doubt that the doctor in the example has a specific form in mind before performing the treatment. He represents this form entirely and consciously. His treatment is designed to actualize this particular form. The question is, what is the form he has in mind? Is it the form of a healthy human being? Restoring the appropriate function of the human body is the product of the treatment. Foster points out, however, that a person owes his or her form of a healthy human being to his or her parents, not the doctor. Moreover, what would it mean for a doctor to have a complete form of human health in mind? It would suggest that with the appropriate materials, it is possible

for the doctor to produce healthy humans. Yet living beings can only be generated by their parents – parents impose their own form on the next generation without knowing or understanding the very form. It is clear that doctors are not able to generate a person even with all the materials at their disposal. The healthy human body does not owe its existence to a physician. The doctor has to know the form of health in a way that she can identify the illness. She also needs to have certain medical knowledge about how some treatments can rectify the unhealthy state. She does not need to know the complete form of the human body, she only needs knowledge of some particular component of it, say the nervous system. Curing is not an act of generation of a living organism – it is acting upon the living organism and restoring a form that has been partially disrupted. When the disruption is beyond a certain point, no doctor will be able to restore the health of the individual. Therefore, we know the doctor is not the cause of healthy organisms: rather, she is responsible for physically curing the organism and getting rid of unhealthy tissues or diseases. The act of the doctor is neither the same thing as the on-going self-sustaining process in an individual organism, nor is it equivalent to generating such a living organism.

The source of natural change is the thing's form, and what it is for. For instance, being a tiger is to have the form of a tiger. The form of a tiger requires the animal to go through the developmental process of a tiger; so being a tiger is the same as growing, aging and dying according to the developmental path of a tiger. The telos of this change is to be a tiger. This process is what it means to be a tiger. Combining the efficient cause with the final and formal cause, helps us to recognize life's specific form- a form with active power. This form is active because it has a transformative power, which can

transform what is not itself to become a part of itself; by such transformation it maintains its transformative processes.

A close look at this idea reveals a serious problem in Aristotle's concept of life in that he is unable to distinguish life from natural changes of inanimate beings. For example, the growth of an apple and the falling from the tree of an apple appear to be the same in the Aristotelian system. The form of being an apple dictates what the materials are of which the apple is made and having those materials requires the apple to ultimately fall towards the ground. Therefore, the falling is also caused by the form of the apple. These two examples can help us distinguish the two different kinds of "moving by itself". Both are dictated by the form of the subject, one is actualized by its material constituent, and the other, following a particular developmental path is what is unique to living beings. Winfield (2018) notes that Aristotle has difficulties in distinguishing these two kinds of motion from each other from the beginning of his study of *Physics*.

What Aristotle fails to do is properly distinguish life from the inorganic processes of nature. He tends to conceive nature in general in terms of what is specifically appropriate to life. That is evident from the very outset of his *Physics*, where Aristotle characterizes what is by nature as that which moves itself according to what form it has. (Winfield 2018, page 7)

In *Physics*, Aristotle emphasizes considering what is most observable to us as the primary source of our knowledge. Also, he takes individuals as the object of study suggesting that the form of a thing can include all the details and all characteristics of

the given thing.<sup>12</sup> This blinds Aristotle to what is unique to being animate, i.e., a particular kind of relationship between parts. The material constituents of an organic body cannot explain their self-motion as a unity. Aristotle believes that the soul is the source of motion, both with respect to place, and in the form of growth and alteration.<sup>13</sup>

### 1.3 The Concept of Life from the Perspective of Possessing a Soul

Aristotle posits the soul to explain why some natural objects alter themselves by assimilating things from their environment, which he believes is the basic motion shared by all kinds of living beings. He claims that “[t]he soul is the cause or source of the living body” (415b9). That is to say, the soul is both the mover of the body, and the end the movement. As discussed, the mover of this kind of change, the vitality of a living body, cannot be a material composition of the living beings. In Aristotle's metaphysics, everything in the world is a combination of matter (*hyle*) and form (*morphe*). Because the soul is not a matter, it must be the form of living things. Form is not separated from the living thing; it is one inseparable aspect of it. The question is whether or not Aristotle has a comprehensive concept of the soul, and if the soul can fully account for all kinds of living beings. Aristotle's appeal to the soul seems enlightening; but he cannot coherently present all aspects of the soul. Aristotle writes in *De Anima* that:

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<sup>12</sup> Aristotle presents his theory of form mostly in his *Metaphysics*. The concept of the form has been used through his study of other things.

<sup>13</sup> *DA* iii 416a4

The soul must be a substance in the sense of the form of a natural body having life potentially within it. But substance is actuality, and thus soul is the actuality of a body as above characterized. (*DA* ii.1 412a20)<sup>14</sup>

The soul is what animates living things exclusively. However, what the general definition of the soul is, and how the soul and the material compositions of living things are entwined, is a difficult problem. Aristotle begins his inquiry by bringing our attention to some essential questions about the soul itself. First, what genus is the soul — substance, quality, quantity etc?<sup>15</sup> Is the soul a potentiality or an actuality?<sup>16</sup> Does the soul have parts or not,<sup>17</sup> and are all souls of the same kind or not?<sup>18</sup>

At the end of Book I of *De Anima*, Aristotle argues for the non-material existence of the soul. It is clear in the case of a house that one can have all the materials of the house, such as bricks, mortar and so on, and still not have a house. The physical parts themselves, i.e., without existing in a specific relationship to each other, cannot account for or maintain the unity of the house. Something non-material is required to account for the unity. The difference between piles of bricks and a house is clear: the bricks need to be organized and structured to become a house which can possess the functions a house is supposed to have. The materials must be arranged in a particular way to actualize the desired function. The function of a house is actualized by arranging materials in a particular structure for a purpose. However, having a spatial structure is

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<sup>14</sup> see also *DA* ii,412a27, 412b3, 412b10; 414a28; *Met.* vii.10 1035b14-31, vii.11 1037a5, viii.3 1043a35

<sup>15</sup> 402a24-25.

<sup>16</sup> 402b1

<sup>17</sup> 402b2

<sup>18</sup> 402b4

not sufficient to actualize the form when we consider living things. Even when we have all the materials at hand, and have configured them in an appropriate special structure, there is still no soul, nor a living body—they are missing something holding them together as a dynamic unity, i.e., an active power to unify and maintain all the materials as an organic whole. Whatever holds them together cannot be something material; then the same problem arises: what could hold this bonding material and other materials together as a whole? Without some formative power, there are only separate and independent materials lying next to each other. Aristotle suggests that an immaterial soul is what holds all the body parts together to function as a living unity.<sup>19</sup> This function is minimally the ability to maintain a constant process of self-renewal by taking into itself what is outside it.

Aristotle recognizes that the word “living” is used in many different senses. He offers a descriptive definition of life, claiming that “that which has soul in it differs from what has not in that the former displays life” (413a23). Furthermore, “we say that a thing lives if any one of the following is present in it — mind, sensation, movement or rest in space, besides the movement implied in nutrition and decay or growth” (413a25). Following this claim, plants have a “principle” in itself which makes them able to grow in all directions. This principle is what makes things alive.<sup>20</sup> He soon reaches the

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<sup>19</sup> 416a8 “They would part from each other, unless there was something to prevent separation; but if there is something, this would be the soul and the cause of growing and of taking in food.” In this paragraph, Aristotle agrees with Empedocles that there are forces that constantly intend to separate living bodies, although he does not like Empedocles’s distinction of up and down through the natural tendency of earth and fire. Aristotle thinks there is a natural tendency which intends to separate organic bodies, and it is the soul that holds each body in unity against the natural tendency.

<sup>20</sup> 413a27 and 413a31

conclusion that none of these features is possible without the capacity of absorbing nutrition.

In the Book II of *De Anima*, Aristotle claims that “the soul is the source of these phenomena<sup>21</sup> and is characterized by them, viz. By the powers of self-nutrition, sensation, thinking, and movement” (413b 14). The power of self-nutrition is shared by all living things; sensation and movements are for animals, and thinking is exclusively engaged in by humans. It is easy to say the soul is the source of all these observable phenomena of life.

Aristotle recognizes three types of souls in life according to their function. They are the vegetative soul, which is responsible for nutrition, growth, and reproduction; the sensitive soul which is for sensation and locomotion, and the rational soul. The last one is responsible for the capacity for thought; which is unique to human beings. Those forms, in Aristotle’s conception, only exist through the material existence of the living things. The soul is responsible for a thing’s being alive, so it is each of the three causations of the entity at the same time: the soul is the form it takes on, the end it exists for, and its essence.

It is clear that the sensitive soul and rational soul presuppose the existence of the vegetative soul, which is also the nutritive soul. Aristotle says “the nutritive soul is found along with all the others and is the most primitive and widely distributed power of the soul” (415a22). Without the self-nutritive power, there will be no sensation for rational activities. The human soul presupposes the animal soul. The three souls are arranged hierarchically. Therefore, the nutritive soul, which is the form of plants, is contained in all

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<sup>21</sup> These phenomena are “The sense of touch and the power of self-nutrition”, which are observed to be the common characteristics for animals and plants. This is stated early in the cited passage. 413b 4.

living things. Different types of souls contribute to the different living functions. Animals have both the nutritive and sensitive souls, and humans possess the rational soul in addition to these two souls.

However, it is questionable how the soul exists in the material body and how different souls coexist in living entities. In *De Motu Animalium*, Aristotle provides a detailed discussion about how the soul can be the source of sensation and locomotion. In our current discussion, it is sufficient to only consider the nutritive soul as this is what distinguishes living from non-living natural things. How does the nutritive soul initiate the assimilation? Assimilation is also a kind of self-motion, although it is different from the kind of self-motion unique to animals.

Aristotle states that by life “we mean self-nutrition and growth and decay” (*DA* ii.1 412a14). Self-nutrition is an active power, initiated by living beings which spontaneously seek and absorb materials from the outside world to renew and maintain themselves according to their particular forms. The process of growth and decay entails a constant spontaneous changing in the material constituents of the living being. These processes involve the whole system intaking nutritive materials and discharging waste as well as conversions between different materials within the system.

The soul, in Aristotle's theory, should be able to account for the particular motions of living beings – self-motion. However, the way in which Aristotle relates the soul to the body makes it unable to account for genuine self-motion. In early discussions of the comparison between living beings and the analogy between living beings and a self-curing doctor, we became aware of two essential characteristics of living beings. One is that the form of the living being must have internally existed in the living being from the

moment it came to be – it cannot be imposed from the outside. The other one is that having a particular way of motion is the very way living beings exist – if the motion stops, they cease to exist. Bringing the soul into the picture, Aristotle posits a mover of this particular motion to explain why it appears to be self-motion. The main issue with this is that a genuine self-motion does not have a separate mover – if the mover can be separated, the motion is not self-motion anymore – it is moved by a mover. Although Aristotle puts a significant amount of effort into presenting how the soul and the material bodies are both essential parts of the unity and thus influence each other, this only explains why the way living beings move seems to be self-motion when it is still, essentially, being moved by a mover. In Book III chapter 5, Aristotle suggests that there exists an immaterial part of the soul, which is the active intellect. This active intellect creates everything, and becomes everything.<sup>22</sup> More importantly, this active intellect, as Aristotle suggests, is “separated, unmixed and unaffected” in relation to material existence.<sup>23</sup> It is also superior to the material aspect of the soul.<sup>24</sup> So in addition to the question of how three types of soul are combined as one, he takes on the burden of explaining how the material aspect and immaterial aspect of the soul are combined as one. In order for the soul to be able to account for the self-motion of living beings, the soul must be the living being itself in an inseparable manner.

The reason that Aristotle needs a part of the soul to be detachable from the material existence is that he still needs a separate mover to fulfill his need of dichotomy

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<sup>22</sup> 430a13-15

<sup>23</sup> 430a17

<sup>24</sup> 430a18

in his theory of motion. Having this structure in the discussion, it is impossible to account for a genuine self-motion. Aristotle provides many detailed discussions of how the soul and the material body are mingled as one, but he still needs to separate the mover as something in the soul which can be detached from the actual existence of the living beings so they can be the moved. Aristotle depends on his theory of the soul to explain the self-motion of organic beings. When Aristotle uses the nutritive soul as the source of motion for all organic beings, he still holds on to something external to the living being to provide it with the ability to change and to move. Aristotle thereby only identifies the cause which allows living beings to undergo their characteristic changes but does not explain the essence of a self-activating system.

#### 1.4 Conclusion

Although Aristotle presents the soul as something that can be thought of as providing us a way of understanding how life operates, this account is still unable to explain genuine self-activation, and self moving. His fundamental understanding of motion demands a dichotomy of active and passive parts in motion. Introducing more media cannot change the mover-moved relationship. It is impossible for Aristotle's theory to account for genuine self-motion – the type of particular motion living beings have. All his efforts in explicating the soul are directed towards finding a mover that can make sense of the way living beings move. Requiring a mover in the picture, Aristotle's discussions always revert back to the notion of craft and the self-curing doctor – either the source of motion is outside the thing itself, or having the particular motion is not the way, *per se*, of its existence.

## CHAPTER TWO

### ON KANT'S CONCEPT OF LIFE

The previous discussion shows that the Aristotelian understanding of nature has two inescapable defects. On the one hand, although Aristotle insightfully brings teleology into the discussion of the concept of life, it is problematic that he applies the same internal teleology too broadly to all natural entities. Aristotle uses external teleology to account for all *technē*, where the purposiveness is imparted to objects from without; while he applies internal teleology, where the purposiveness is within the object itself, to all natural entities, stones and animals alike. Therefore, his concern with teleology cannot distinguish living things, such as animals and plants, from inanimate natural entities such as stones and fire. On the other hand, the analogy Aristotle draws between certain examples of inanimate objects and internal teleology reveals a fundamental mistake in using his concept of internal teleology to identify living things. To present the concept of internal purposiveness, he uses examples such as self-healing doctors and self-building houses to explain internal purposiveness without realizing that the examples essentially involve the exercise of *techne* which always has a product in which the making is extinguished, unlike living entities. Although Aristotle successfully recognizes that there are particular characteristics that living things possess exclusively, he presents them such that they apply to products of making. An appropriate concept of internal teleology could be the key to distinguishing animate from inanimate beings;

however, the internal teleology as Aristotle presents it does not provide that differentiation.

## 2.1 Kant on Teleology

To further explore teleology in our inquiry into the concept of life, we should turn to Kant, who fruitfully distinguishes two different types of teleology, i.e., external and internal purposiveness. Kant elaborates these concepts more fully and clearly than Aristotle did and addresses the problems mentioned above. It is crucial to note that in the Kantian system, the structure of our cognition is restricted. For Kant, the only objects knowable by us are material objects of experience which are subject to universal external necessity. The universal and necessary knowledge we can have about objects applies to any possible object of experience no matter what it is. This tells us that what pertains universally and necessarily has nothing to do with what kind objects are, to which genera and species they belong — none of this can be known with any necessity and universality. For Kant, the only *a priori* knowledge we can have about objects is that they are governed by material law. Material law concerns exclusively the locomotion of bodies considered as matter, i.e., undifferentiated objects. It applies to physical objects of experience no matter what form they may have. In other words, in Kant's epistemological framework, we cannot know makers with designs in their mind, functions of objects, or things with either internal or external ends. Moreover, we cannot know organisms in this framework since we can only address mechanical motions which are no different from those of non-living objects. This limitation is determined by the structure of knowing which applies to all objects of knowing. Law has nothing to do

with specific form; it only works on objects insofar as they are material entities, without further qualifications. This also means that if we are concerned with understanding what law will determine them, our concern will be not with their natures, but only with changes in their spatiotemporal location. For Kant, these are the only kind of laws of nature we can know of, and the only aspect of the objects of which it is possible to have some necessary universal knowledge. Kant develops his causal system on this basis, conceiving nature to be a mechanism of inertial locomotion. Any change in motion is determined by something external to the object which undergoes the change. It is therefore questionable how knowledge of teleology, especially internal teleology, is possible in Kant's epistemological framework.

Kant nevertheless employs two kinds of purposiveness, i.e. external and internal purposiveness. He applies the former to the processes of making in the arts and crafts, while employing internal purposiveness to conceive living things. In Kant's discussion, self-healing doctors, like other examples Aristotle uses to describe internal purposiveness, remain caught in the process of making, because they involve relative purposiveness that is outside the object to which it applies. Relative purpose is an end that is external to an entity. Living beings can have relative purposiveness, in addition to their internal purposiveness, such as by being some other animal's food. In contrast, the internal purpose of living beings is not relative to other entities: they have an internal principle aiming at sustaining the functions that maintain their unity. For example, the organs of a living organism exist for the sake of the functioning of the organism as a whole, while the whole exists for the sake of each part. The external purposiveness of a thing depends on its relationships to other factors, while its internal purposiveness

depends on what it really is by itself. Kant introduces internal purposiveness in departure from the purely mechanical understanding of nature in which everything is determined completely in terms of cause and effect.

For Kant, what is knowable of nature is no more than a domain of things that are governed by material laws. These laws have nothing to do with the species or forms of objects. However, from his experiences, Kant recognizes that there are some characteristics of living entities that cannot be fully determined by material laws. In section 65 of the *Critique of the Power of Judgement*, Kant presents a substantial account of his understanding of life in the light of causation and purposiveness. Denying any analogy between organized living beings and art, Kant claims that the causality of living beings is different from external teleology as well as from the causal relationships we find in the rest of the natural world. The key difference between internal and external teleology is that the artist/craftsman is outside the product that is produced whereas the living thing operates as an end in itself, sustaining its own life processes. Although the analogy between art and life can shine some light on understanding the teleological nature of life, it misses the most important link, which is the way in which life's active principle and material matter connect with each other. Kant suggests that if we consider matter as matter *per se*, then it will have no power to play the role of craftsman. Matter will not be organized as a living being by itself; while if we presuppose that the matter of living beings is matter with special power, such as that of an innate soul, then such an analogy will be fruitless since it reveals nothing new about life. Kant concludes: "Strictly speaking, therefore, the organization of nature<sup>25</sup> has nothing analogous to any causality

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<sup>25</sup> In this context, the organization of nature is organic organization.

known to us" (375:7).<sup>26</sup> Being aware of this problem, Kant invokes internal teleology to address this particular self-causing relationship.

Kant locates internal purposiveness exclusively in three identifying aspects of living entities. Objective experience cannot provide Kant with any genuine knowledge about the essence of living things, because everything we can experience is mechanistic in nature. Nonetheless, Kant draws upon his experience to make sense of processes which seem to be fundamentally different from purely mechanistic changes. Kant reflects upon his experience of trees to show there are some non-mechanical features in the life processes of trees. This chapter will examine Kant's discussion of these organic processes of trees to determine whether his reflections on them are legitimate within his system, and how much his conclusions shed light on life.

Despite maintaining a material understanding of the natural world, Kant acknowledges that we experience things in the natural world, e.g., animate things, which mechanical laws cannot fully account for because their change cannot be reduced to locomotion. Kant brings in the concept of teleology to solve this problem.

Kant uses the concept of life in three different senses: the ethical, biological and aesthetic sense.<sup>27</sup> The biological concept of life is the one we will discuss here. This biological understanding of life focuses on how to address life on its most fundamental level, i.e., as individual organisms. Kant turns to internal teleology to account for the phenomenon of life. As we saw in the previous section, Aristotelian teleology fails to

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<sup>26</sup> In the rest of this Chapter, I will only use page reference for quotations of Kant. The page reference is that used in Kant and Walker (2007) listed in the Works Cited section at the end of this dissertation.

<sup>27</sup> Ethical understanding is the practical use of the concept concerning humans' ability to act voluntarily; the aesthetic definition relates to the feeling one could experience when facing beautiful objects. These two will not be discussed.

distinguish life from other natural entities since it assigns a unified purposiveness to all natural beings. Every natural entity, a stone and a tree alike, has a purpose, to fall or to live. Kant's theory of purposiveness is an advance on Aristotle's in that it identifies two different kinds of purposiveness, i.e., external and internal purposiveness, and applies internal purposiveness to life in general — this purposiveness is impartial to the material worked upon by the external maker.

Kant's discussion of purposiveness begins with the distinction between formal purposiveness and material purposiveness. Although they seem to resemble Aristotle's formal causation and material causation, they have a different focus. Aristotle's "formal" and "material" causes concern about what determines things to be the way they are. The formal cause of a statue, for example, is the design in the artist's mind; the material cause is the plaster or bronze of which it is composed. In contrast, Kant's formal purposiveness and material purposiveness concern one thing's ability to produce external results. The material purposiveness of the statue, from the artist's perspective, is to gain more money and fame; the formal purposiveness of the statue is to delight people who can appreciate it. Kant points out that the formal purposiveness is not real because "it is a purposiveness which does not imply an underlying end, and which, therefore, does not stand in need of teleology" (364:5), whereas the material purposiveness "is real, and, being real, is dependent on the conception of an end" (364:26). Beauty, for example, is not a genuine quality that exists in the thing outside me "but a mere mode of representation existing in myself" (365:7).

Material purposiveness involves a concrete cause-and-effect relationship. According to Kant, there are two possibilities for its effect. In some cases, "we may

regard the effect as being, as it stands, an art-product” (367:5). In the rest of the cases, the effect is produced by other possible objects as their art-product.<sup>28</sup> The second purposiveness is known as utility when it concerns humans, and advantageousness when it concerns any other creatures.<sup>29</sup> Kant points out that one thing’s being useful to something else does not make it less an end than those which are not useful to something else. He writes

in the series of the mutually subordinated members of a connection of ends each intermediate member must be regarded as an end, though not a final end, to which its proximate cause stands a means. (367:40-368:3)

For example, sand, which is an example used by Kant, is the result of the sea’s movement, and can be a cause of the thriving of certain desert plants. The purposiveness based on its advantageousness is not “an immanent objective purposiveness of things” (368:9). If A appears to be causing B,

Therefore, the advantageousness of a thing to some other things, approximately or remotely, is the core for having extrinsic purposiveness. Therefore, this kind of purposiveness of a thing depends on its accidental relation to something outside it. The sand’s being useful for desert animals is not intrinsic to its identity as sand. Hosting desert animals or not, the sand would not be more nor less sand. This kind of purposiveness depends on an object’s relation to something external to it.

In contrast to this kind of external and accidental purposiveness, there is the other type of purposiveness where a thing serves as an end in itself in a necessary

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<sup>28</sup> 367:6-8

<sup>29</sup> 367:10-12

manner. That is intrinsic purposiveness. The existence of this purposiveness is independent of something's relationships to others. The existence of intrinsic purposiveness and the meaning of it is clear if we think about its relation to relative purposiveness. As Kant suggests, if the sand does not look to an end nor has an end in itself, it cannot be conceived as the effect of the sea. That is to say, the relative purposiveness depends on things that have intrinsic purposiveness: it is impossible to have only relative purposiveness. Having intrinsic purposiveness involves a "capacity of acting that is determined by concepts" (370:2): this capacity makes something with intrinsic purposiveness what it is. The sand's being the habitat for desert animals is not determined by the concept of the sand – it is merely an accidental connection. To host desert animals is not what makes sand, sand.

## 2.2 Kant on Self-causing

After distinguishing relative and intrinsic purposiveness, Kant brings in the concept of natural end: "A thing is possible only as an end where the causality to which it owes its origin...in a cause whose capacity of acting is determined by concepts" (370:1). There are two types of things that can be considered as having an end in itself – natural entities or processes that appear to function towards a purpose, and human-made artifacts. They can be useful for others or not, but they definitely contain an end in themselves. However, the artifacts do not have a natural end because they imply an external designer. In order for something to be regarded as a natural end, Kant points out, it needs to be "both cause and effect of itself" (371:1). This concept might seem

incomprehensible, but it can be “thought without contradiction” (371:5). The cause and effect of trees are the example Kant uses to illustrate this.

Kant suggests that trees are self-causing in three respects. First, trees are self-causing on a species basis: an individual tree generates another individual tree according to the nature of the species of the tree.<sup>30</sup> Here the self-causing entity is the species but not each individual tree. One tree, as a member of this species, causes another tree, which belongs to the same species. In this sense, the species is “continually generated from itself and likewise generating itself” (371:11) through reproduction.

Second, a tree is self-causing in the sense that it is the cause of its own growth. The growth is different from reproduction; it is an internal change which does not involve another individual tree as reproduction does. Kant emphasizes that growth, in this discussion, is “entirely different from any increase according to mechanical laws” (371:15) – it is essentially generation. A tree “develops itself by means of a material which, in its composite character, is its own product.” (371:5). It is impossible for us to “reconstitute those products of the vegetable kingdom out of the elements which it obtains by its decomposition or else out of the material which nature supplies for its nourishment” (371:5). This is rooted in the essential difference between living beings and artifacts. An artifact only has a passive form, which is a specific kind of structure that is imposed upon it by a maker. This form is universal in character – it is common to any artifacts that are made according to the same design. The same form can be embodied by the maker using any appropriate materials. That is to say, it is possible for

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<sup>30</sup> 371:8

any maker with the particular form in mind and materials at hand to make an exemplar, and produce infinitely more examples. In contrast, each living being has its individual and active form that cannot be embodied as an antecedent design in other materials. In the case of plants, growth results from a process that involves the plant absorbing materials from the outside and giving them its own active form. This may even include reducing its size (as trees shed leaves in the fall) or ceasing to be active (when dormant in winter) in some cases. The form is not imposed by another object of a different type, but by the active form that the tree itself possesses. This active form is what makes the tree what it is. It is not only causing the tree to reproduce and grow; it is also, as the essence of the tree, the result which is being caused. Many plants grow, in the original meaning, throughout their life: they not only increase in size, but also grow new organs. They grow more roots, leaves and branches in maintaining themselves. The situation is different for animals. Almost all animals stop increasing in size after an original growing period. After that period, they either maintain that body size, or lose it to a certain degree. It is also very rare for animals to grow new organs. Some animals can regrow their limbs after losing them to survive in dangerous situations; however, this is still different from how the trees grow.<sup>31</sup> Growing new organs is part of the way of being a tree, whereas the way animals regrow lost limbs is essentially repairing themselves to return to their original form – in most of the cases, the ability to regrow or repair damaged limbs or organs are very limited. For example, human beings cannot regrow lost limbs or damaged organs. Animals will not grow more limbs than the number they are supposed to have. Moreover, trees can regrow all of their organs, roots, branches

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<sup>31</sup> UCSB Science Line

and leaves, whereas animals can only regenerate very limited kinds of organs. The regenerable organs are normally simple and unified organs. In most cases, animals can live without these organs. Lizards can survive without tails and starfish can be equally viable with or without half of their bodies. Animals cannot regenerate essential organs such as hearts. Although the body can repair certain tensions when necessary, it is impossible to regrow the whole organ in the way plants grow leaves.<sup>32</sup> Whether plant or animal, growth means maintaining the ability of organisms to impose their own active forms upon the appropriate materials in their surroundings that are metabolized.

The third type of self-causing is the reciprocal relationship between each part of the tree: each part of the tree itself persists by relating to the other parts of the tree in a reciprocal way. One part of the tree works as the means and the end, simultaneously, for the other parts of the tree. Parts of such an organic unity are considered organs as they constantly are maintaining, repairing and sometimes producing each other. In the case of trees, leaves and roots are two parts of the trees which have such a reciprocal interdependent relationship. The leaves enable the root to function well. There are two reasons for that. Leaves manufacture food, through photosynthesis, for the whole plant. Plants cannot remain alive without those nutrients. In addition, the transpiration of leaves provides the necessary pressure for the water circulation system in the plants. Without this pressure, roots cannot have the absorbing power required to fulfill their function, i.e., absorbing water and nutrients from the soil (or the water/air in some cases). Meanwhile, leaves cannot function without the water and nutrients absorbed by the root. The roots and leaves are maintained and produced in function of each other.

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<sup>32</sup> This interdependency will be further addressed in the next paragraph.

This connection is actualized and maintained by the organic unity of which they are constituents. Parts of the whole assume complementary functions in sustaining the whole. If all parts of the tree are roots neither the tree nor the roots can fulfill their functions. The roots cannot absorb nutrients and water from the soil since they depend on the photosynthesis to stay functional; whereas the organic unity does not exist anymore since it is essentially this reciprocal interdependent relationship between complementary parts. Each part assumes a particular role in the whole; it is the inherent cooperation of the parts that enables the whole to pursue its purpose.

We will see that the second type of self-causing, as described by Kant, is the only essential character that is shared by all living beings. The situation is different for the other two life-processes: reproduction is not shared by all living individuals; and the necessity of reciprocity between parts varies significantly in each case.

The way the tree causes itself is determined by its being a tree – it is not accidental. Moreover Kant points out that things that can be considered as natural ends have parts whose form and existence “are only possible by their relation to the whole” (373:2). Every part of these things is thought of as “owing its presence to the agency of all the remaining parts, and also as existing for the sake of the others and of the whole” (373:36- 374:1).

To evaluate Kant’s three internal teleological processes of living things, we have to examine if they are indeed irreducible to mechanical processes. The three processes,

described by Kant are merely<sup>33</sup> abstractions of his experience of trees. He identifies the three characteristics of life by describing aspects of trees that do not follow mechanical rules. The reason why Kant relies on his experience with the tree to develop this concept of natural end is that such a concept, in his words, is “not a constitutive concept either of understanding or of reason” (375:19). The adoption of such a principle must be derived from such experience, namely, “as is methodically pursued and is called observation” (376:16). Because machines can actualize everything that can be fully accounted for by material laws, Kant compares the processes he finds in his experience of trees with processes of machines to show that the former go beyond mechanical laws.

The relation between the parts of machines and that between organs of living systems are fundamentally different. On the surface, they both involve a reciprocal relationship. In each one, part of the system is the cause of the proper functioning of other parts; meanwhile, the functioning of this one part is also the result of the function of all the other parts of the system, whether machine or living entity. The reciprocal causal relationship between parts of a machine is nothing more than efficient causality, governed by material necessity; while that between parts of an animated being have an additional reciprocal formal causation. This reciprocal causation is not limited to maintaining certain functions, it also covers repair and growth (both in size and in

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<sup>33</sup> We should always be aware that everything Kant has to say about the life process merely takes the form of thoughts. He cannot treat them as a body of knowledge because strictly speaking we do not have genuine knowledge about life on his terms: we can only have knowledge about mechanisms. Everything Kant presents are only ways of thinking about life based on his limited experience of mechanical aspects of life, but not knowledge about life *per se*. Kant’s concept of life has at least two defects. First, it does not have the universality a concept should have. Kant’s concepts are based on his experience of trees. It does not include animals, or plants other than trees. He does bring in his observations of some other organic units to his discussion. However, the universality of his concept cannot be guaranteed by these additions.

gaining function) of the parts. As Kant claims that organs not only depend on each other for their existence and form, they need to constantly and reciprocally produce each other.<sup>34</sup> Taking animals as an example, certain malfunctions of an organ can be repaired by the work of other organs. Similarly, the organic system of the living organs can in some cases result in their causing each other to grow in size and mature. Such relationships can only happen in organic systems, and have to be maintained in an organic system by allowing the parts to function as themselves. These special characteristics of parts of living beings lead us to note another difference between organic and inorganic beings: organic beings produce themselves while undergoing change, whereas machines produce products other than themselves while they remain untouched themselves. In other words, the product of the function of a living being is the living being itself. The material components and function of the living being are caused/produced by their own function. This is a kind of formative power where the products receive the form from the living being itself. In contrast, the material existence of a machine is completely independent from its function. The machine remains as it is before, during and after the process of its use because what it produces will not become a part of the machine in a necessary manner.<sup>35</sup> It is possible that one machine happens to produce the parts it may need to have replaced at some point. Yet, using the part that is produced by this very machine or using a part that is produced by a different machine makes no difference to the repair; and the part can be placed on a different machine to

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<sup>34</sup> 373:2 and 374:5.

<sup>35</sup> It is possible that the machine is worn down or broken when it is working, however, this is different from the changes in this discussion because such changes happen in an arbitrary manner: the functioning of the machine does not dictate the wearing-down in a necessary manner – there is no direct causal relationship that will lead to the wearing-down.

function in the same way, or can be discarded. Being used in the machine which produced the part is not inherent in the part's being what it is. Moreover, the parts are produced before they begin to function the machine. The existence of the parts is independent of the existence of the assembled machine. In cases where the machine happens to produce parts that can be used to replace its own broken parts, such production and replacement is still different from the way a living organism repairs itself because the end of the part production is not the machine itself, but a product that has no inherent connection to the machine itself. An external agent is required to install the replacement parts according to an antecedently determined design. The efficient cause of the machine's repair is outside the machine, while for a living being it is inside itself. This internal power also reaches outside a living being to seek materials and energy to maintain itself. It will obtain what it needs from its environment, whereas machines do not have such initiative power of using what is outside them to maintain themselves, because machines have no such active unity as selves to be maintained. Whatever modification is done to the machine is initiated outside the machine for the sake of an end outside the machine. Although there are changes, such as rusting and wear, which seem to happen spontaneously in machines, they are still external changes. Rusting is not an assimilation initiated by the machine as a machine – it rusts as a metal.<sup>36</sup> It is initiated by the chemical reactions between materials.

It is possible to have a machine which is programmed to produce more machines like itself. With contemporary technologies, there should be no insuperable obstacle for the original machine to move the newly produced machine to an appropriate location

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<sup>36</sup> A similar example would be, when we burn a wooden table to stay warm, the table is burned as wood, but not as a table.

and turn on the power to set it working. This seems very similar to the reproduction procedure. However, to have a certain structure and to produce the same machine is external to the machinery which is produced by the machine. No matter how machines are able to produce more working machines that are like themselves, the structure and the end of the machine are always outside itself. The original machines gains its form from an engineer, and it does not come up with the idea to produce more machines for its own purpose. An engineer wants to solve a problem. So he designs a machine, with a particular structure he has came up with, to fulfill an end, i.e., solving the problem that exists in his mind. None of these procedures are “in” the machine-to-be-built. It is the same situation for the machines which are produced by the original machines, they are essentially materials with an imposed form. By contrast, forms of offspring produced through reproduction are internal to the parents. Although their offspring will eventually become external existences, the reproduction involves part of the parents. In addition, the product of reproduction is pre-determined by the parents’ form: the parents and the offspring are automatically of the same species. A machine may or may not be designed to produce other machines like itself; this depends on the engineer’s plan but not on the machine itself.

Laying these thoughts on the table, Kant is in an excellent position to overcome the problems with Aristotle’s example of a self-building house in his discussion of the internal end. The problem with Aristotle’s strategy is that the internal end is not the same as the purposiveness of any inorganic system. In section 65 of the *Critique of the Power of Judgement*, Kant examines the construction of a house to clarify the particular reciprocal relation in living things. Kant points out that the house is the cause of the

rental income while the rental income is the cause of building this house. There is an apparent loop in this causal relationship but this is still an efficient causality. In the case of a causal nexus “the things that as effects presuppose others as their cause cannot themselves in turn be also cause of the latter” (372:23). The construction process is done by builders engaged in activities that are not a part of the house’s being the house. The builders’ activities end with the production of the house. However, they built the house to rent it. This is the final causality in this scenario. This causality is separate from efficient causality. Although the rental seems to be the cause and the effect at the same time, the rental is not an end itself: it is not the end because individuals outside the house want to have the rent. They may or may not spend it on the house, but their concern is their pursuit of profit or happiness. This is an example of a final cause (*nexus finalis*). Such causation is different from efficient causality because efficient causality involves no purpose in any way, neither internal nor external. The purpose of living things is built into the living organism. It is something that realizes its own end which is the realization and maintenance of itself. The agency of this house-building is outside the house. There exists someone who implemented a build-rent relationship to actualize a purposiveness in his or her mind.

In contrast, in an organic system with a natural end, the “parts, both as to their existence and form, are only possible by their relation to the whole” (373:2) and are combined into a whole by being reciprocally the cause and effect of their form. The form of the house, in the previous example, does not originate from the house but was from the architect’s minds. Winfield 2018 suggests that

[a] key difference noted by Kant is that the parts of an organism produce one another and the whole, rather than being produced by some external agency that designs them and that then makes and assembles them into the whole. (Winfield 2018, page 47)

Parts of a machine exist before integration into the whole. They are produced in accordance with designs in the mind of the makers. The parts of machines have their identities separately by themselves. In contrast, whatever parts there are in the organized being are only produced by the living system itself to actualize ends internal to the living systems. Parts of the living system cannot be produced separately in the same sense as parts of machines. It is impossible to produce, say, a living hand in isolation from a living body. A living hand only has its full functional identity when being a part of a living body. Life cannot emerge from assembling inanimate parts according to some plan given outside the organism because there is no such thing as separate pre-existing organs of a living body. A screw is completely a screw before being, during and after being a part of a mechanical system. Organs of living systems only exist, *per se*, when they are functioning as parts of the living system. Once the unity of the organs has ceased to function, it becomes a chunk of chemical material and undergoes some processes of decomposition. No longer part of the living system, the organs can neither continue to function as they are meant to, nor maintain their chemical and physical states. Being a part of a living system is the only way the organs of a living system can be and maintain themselves.

Another obvious difference between machines and organic beings is that machines can be turned off while organisms cannot. The latter have an active form

which can only be maintained by continuously exercising it. We do have plants and animals which seem to pause their active form in a certain state of dormancy. However when those plants and animals have completely lost their active form, there is no way for them to reactivate it. Dormancy is only a special temporary function dictated by their active form to better maintain that active form. Maintaining dormant states is a way to function. Although living beings in dormancy do not have to eat and move, they are still maintaining their living power, unlike inanimate beings. Hans Jonas identifies life as being able to maintain an energy flow. To be alive is the same as letting the energy flow; once the flow stops, life disappears.<sup>37</sup> Machines use energy as well, however, the energy flow is not generated by the machine itself – it requires storing potential energy outside the machine to start and maintain the flow. As soon as the energy input stops, the machine ceases to work while the machine itself stays unchanged in that it can restart only when the required external condition resumes.

Hans Jonas has also systematically compared machines and animated beings in *The Phenomenon of Life* (2001). Benefiting from advanced scientific knowledge, Jonas's comparison between metabolism and the functioning of machines is generally the same as Kant's. Jonas discerns "special goings-on"<sup>38</sup> both inside and outside the boundary of organic beings. He refers to an organism's metabolism as "its exchange of matter with the surroundings" (Jonas 2001, page 75). Through the constant change of the material identity of the living form: "it sustains its own identity by the very act of foreign matter passing through its spatial system" (Jonas 2001, page 75). Jonas points

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<sup>37</sup> Jonas 2001, page 76 footnote 13

<sup>38</sup> Jonas 2001, page 75

out that if the material contents of an organism are the same at two different time slices, it ceases to live. Living systems have an all-pervasiveness of metabolism. By contrast, Jonas points out that the parts of a machine are not affected by the energy (e.g., fuel and electricity) flow through the machine.<sup>39</sup> The material identity of the parts stays the same regardless of what happens to the energy flow through them and the function they perform in these processes. The machine parts remain the same even when nothing is flowing through them. In comparison, in a metabolizing system, all the parts of the system are “wholly and continuously” (Jonas 2001, page 75) the products of the metabolism they are involved in. Metabolism continually builds and replaces the parts of the living bodies. When a living system is at a standstill, it is not a living system anymore. Although Descartes suggests that living beings are merely machines that burn food for energy, Jonas points out that metabolism is more than a source of kinetic energy. In addition to providing energy, metabolism continuously replaces and repairs every single part of the living system. If a living being were a machine, the operation of the machine would consist in becoming itself, which, Jonas concludes, is impossible in a mechanistic operation.

The question whether or not reproduction is a necessary condition for organic beings is not as clear as the necessity for metabolism. There are animals born infertile, e.g., worker honeybees. Moreover, organic individuals can lose their fertility during their lifespans for both expected and unexpected reasons. Many organisms that can reproduce retain that capacity only during a certain period of their lives. This ability is meant to wither as the organism ages. The ability to reproduce may also take time to

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<sup>39</sup> Jonas 2001, page 75

mature. The organisms are expected to function following this timeline: losing the reproductive ability is a part of being what they are; though there are cases when an organism loses its fertility because of unexpected damage or illness. So we have several different types of infertility: some organisms are sterile at birth, some lose their fertility by accident, some have the potential for it, but do not yet have it actualized, and some had it, but lost it through accident or illness or as a natural process of their aging. Thus the ability to reproduce is not indispensable for life at least for an individual organism. However, can we have life without reproduction in general? When we have such a stable community of living beings, the existence of some sterile individuals is negligible for the continuity of life. The situation is different when we consider the beginning of life. In an utterly inorganic world, long before a stable living community has been established, does a single, briefly existing, organic being without reproduction qualify as a living being? This single individual, without reproductive power, is just as alive as other individuals with reproductive power, with or without offspring. However, there is a difference in terms of the viability of life in general – if the whole group of living beings is infertile, the group is less viable compared with those groups whose individuals can reproduce. With this in mind, reproduction is a sufficient condition for being alive – things that can reproduce must be alive, whereas it is not a necessary condition for being alive – things that cannot reproduce/do not reproduce may or may not be alive.

Nonetheless, among all the life forms that we know of, we should be aware that having offspring is only one part of the reproductive function. Each individual has two ways to be involved in a reproductive relationship, one is to generate another living

being, the other is to be generated. We already know, from the previous passage, that generating a living being is fundamentally different from any other kind of making, regardless of whether made by a craftsman or a machine. Making is a very specific process whereby artifacts are produced, but living things are not artifacts. Although we have little knowledge about how life came to be at the beginning, the first instance of life was neither born, nor made – being born requires parents with the same form, whereas being made suggests an intelligent design with a pre-existing form of the product. The process of making requires a maker who does not make herself/himself. Living beings cannot be made as artifacts are made where an external maker imposes a pre-existing form different from its own form, upon the material. Although Kant has no knowledge about how such a creation is carried out in an utterly inorganic world,<sup>40</sup> this spontaneous generation of organic beings is necessary for the existence of any living beings, including those that briefly existed in the otherwise inorganic world with no reproductive power nor any offspring. Abiogenesis is the study that aims to determine how pre-life chemical reactions can give rise to the life-forms we have today. Scientists have been trying to produce organic entities in laboratories<sup>41</sup>. As scientists working on producing life in laboratories to study the origin of life, we once again face the question of the criteria of being alive. Although this question is still controversial, scientists generally agree that having metabolism is what they need to achieve in their attempt to produce life in a lab. It is safe to conclude that this initial “generation” is not an appropriate

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<sup>40</sup> Presenting it this way, we assume that there was an utterly inorganic world existing before the existence of organic beings, and organic beings come to be from such an environment. We cannot take it for granted without further evaluation. However, whether or not it is the real situation does not impact our emphasis on the productive power of the concept of “reproduction”.

<sup>41</sup> This will be discussed in more detail in Chapter 4. Understanding the Jump to Biology.

example of self-causing; however, it is an inherent property of life which cannot be accounted for by material law.<sup>42</sup> It is not an instance of self-causing because the organism was not yet there – it was produced out of something that is not alive. The first living being arose from processes involving nothing other than mechanical and chemical reactions – these reactions are externally caused, but not self-causing.

Living beings are not made out of inorganic parts because organs of organic beings are essentially different from parts of inorganic beings, which alone can be made. To make an artifact, the maker produces it part by part. Each part is able to perform its function before being a part of the final product. Therefore, each part can be produced independently, and individually. However, all organs of an organic unity need to be present at the same time, in a particular interdependent relationship. They have to start assuming their function all together at the same time. Failing to do so, the material constituents of the organs are not sufficient to make the organs assume their functions at all. This is why organic beings can only be generated as a whole but can not be made, nor produced, part by part.

Now let us move on to the next process Kant addresses, namely, the particular relationship between the organs of organic beings. From the discussion early in the chapter of the relationship between parts of machines and that between organs of living beings, we can claim that this particular relationship between parts is a sufficient condition for life. As long as the parts of a system have this complementary, reciprocal relationship – parts of the systems under this relationship are organs of unity – the

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<sup>42</sup> This question about how organic beings come to be from an inorganic world cannot be settled in Kant's epistemological system, because he treats organic entities as unknowable in the knowable inorganic realm. This issue will be settled as we turn to Hegel and Jonas in the following chapters where Hegel will expand the knowable realm to include chemistry and Jonas will use autopoiesis to bridge the gap.

system is fundamentally different from a mere mechanical system. Organs are in complementary relation in the sense that each of them assumes different functions which are necessary for the unity of the whole. No one organ can assume all the functions by itself, because organs are differentiated materially, and functionally, and each organ can only perform its unique function by being a part of the whole. Organs are in reciprocal relationships in the sense that each causes the identity of the other organs in the system as well as being caused by the others. Consider the reciprocal relationship between organs of a human as an example. If the heart stops functioning, the rest of the systems will stop correspondingly; meanwhile, the function of the heart is conditioned on the functioning of all the other organs in the system. The situation is the same for each and every organic constituent of the system.

It is worth noting that the complementary and reciprocal causal relationship between the organs is different from the other two identifying aspects of life Kant mentioned, because the interdependence of parts of one form of life is different from that of other forms of life. Organs of an organic system are differentiated from parts of machines in the sense that they are in a reciprocal and complementary relationship where the interdependency varies between different life forms and between different organs. For example, the interdependency between parts of plants is much weaker than it is in animals. Animals cannot survive the loss of the heart yet in most cases, plants can regrow leaves and roots with the appropriate external conditions. Plants can even freeze completely in a certain environment in the sense that their organic system pauses completely and comes back alive when the right environment is provided. Plants without leaves or roots have other organs that can assume their missing function

temporarily to earn some time to regrow them. For example, in propagation by cuttings, if the cut stem does not grow roots after a certain amount of time, the stem will die. Therefore, to have a stable and proper living situation, the plant needs to have all the organs it depends upon. In addition, plants normally have multiple organs to assume the same function which weakens the dependency on each one of the organs. The case is different for animals because some of the most essential organs for the survival of animals are always unique, and cannot be regrown after they are lost. Moreover, animals depend on certain parts of their body more than other parts in most cases. For example, humans depend on their hearts more than their stomachs, although both are essential organs of this organic unity. Losing the heart, an individual ceases to live; losing the stomach, one can still survive with a specially designed diet – the life-quality is compromised, but survival is still possible. All forms of life need to interact with their surroundings to obtain what they need to maintain and repair themselves. However, the complementary interdependency between parts of organic beings varies between animals and plants and even between individuals of the same kind. Regardless of those differences, the key to maintaining survival, for both animals and plants, is still having these reciprocal and complementary relationships between the organs.

The reciprocal relationship of organs is necessary for life. However it does not apply equally to all parts of the organic beings. For example, plants trimmed low for the winter with only roots, but no leaves left, still survive. Having leaves is not necessary all the time; and no one leaf is irreplaceable. Kant takes this relative independence as a particular characteristic of plants that other living organisms, e.g. animals, do not

share.<sup>43</sup> He uses grafting to show that certain parts of the tree have their own independence because they may grow and function as a whole tree by absorbing nutrition through the roots of another plant.<sup>44</sup> Furthermore, there are plants with even more independence. For example, many *Lamiaceae* and *Epipremnum aureum* can grow from a cutting in water or soil. Compared with grafting, this growth does not require another plant to which the cuttings are attached. If we consider this interdependency between parts of a plant to be relative, then absolute interdependency can pertain to the vital interdependency between certain parts of an animal. Certain parts of animals are indispensable because animals cannot regenerate them, nor do they live without them. Damages to the heart, for example, can cause death of the animal.

Let us take a horse as an example. A horse without one leg or four legs can be as alive as a healthy horse if we consider its metabolic ability. Health in this context does not concern functions such as running, but only its ability to interact with its surroundings to maintain its life. However, the horse loses certain essential functions which it cannot regain easily. This correlation is very different for a plant: losing some leaves or all of the leaves will not compromise its function: either other leaves can compensate for the function efficiently, or leaves will be regenerated when the time comes. Kant is aware of this relative independence in the reciprocal independence he presents. He uses parasites to describe the grafts growing on a different plant. He suggests that being grafted or not, parts of a tree have the potential to live as

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<sup>43</sup> Losing an essential functional part can be a serious damage for animals, whereas plants do not suffer from losing leaves or some of their other functioning parts, e.g., stems, roots.

<sup>44</sup> 371:5

independent living beings. Winfield (2018) concludes that “the relative independence of parts that Kant describes is not generic to life, but a fixture of a certain life form that a philosophical botany may address” (Winfield 2018, page 39). We should note that although parts of plants seem to be less independent of each other than parts of animals, neither has absolute dependency: they only have partial independence at different levels. Only the organic systems that cannot lose anything without losing organic characteristics have an absolute dependence between their parts. It is an extremely economical system in which every single piece is necessary. Animals cannot survive if they lose certain body parts; however, we often overlook that plants are the same. Although some parts of plants, after being gutted off from the main body, can still be alive in the sense of being able to generate a whole independent plant, this only happens to certain parts of the plants, and under certain conditions. Some grafts may not survive because of the size or the lack of necessary functioning parts. Grafts need to have certain parts/functions to survive. It is clear that both plants and animals have the reciprocal dependency Kant addresses, although on different levels.

Kant does notice the difference in dependency among parts of plants and parts of animals; however, he does not use his teleology to account for this kind of hierarchy of internal interdependency between various forms of life. On the one hand, such work is unnecessary because this hierarchy will not impact the universal existence of interdependence in living beings; on the other hand, Kant is incapable of discussing more on this issue due to his insistence on a mechanical understanding of the natural world. For Kant, the mechanism of the world is the only possible subject of our knowledge, and life itself already lies outside this realm: it is problematic to discuss

more about the essence of life by merely reasoning, due to the limitation of our understanding.

Reproduction, where a member of a species generates another member of the same species, is not essential for individual living beings but is essential for their sustainability and adaptability. Species is one of a kind through reproduction. A living individual does not necessarily belong to a species. The first living being emerged from the inorganic world, and the last living individual in an extinct species is alive without belonging to any species. The former one will belong to a species only when it acquires the ability to reproduce and does so. The latter one belongs to a species when there have existed other individuals who connected to it through reproduction – its parents, cousins and other relatives. For a species to actively cause itself, as Kant suggested, individuals of this species have to undergo reproduction regardless of the form of life they take.

Growth, in Kant's sense, is indispensable to all living beings. However, this conclusion is only viable for plants. Self-maintenance through metabolism is indispensable to all living beings, yet, plants might be the only type of living beings for whom being alive is always associated with growth. The growth Kant finds in his experience of trees is similar to metabolism in a modern sense. Although Kant does not know biochemistry, which we use to explain metabolism, he does see the essential point of metabolism: to assimilate things from the organism's surroundings to maintain its active form, which involves the ability to assimilate. However, Kant does not notice that this kind of self-maintenance through interaction is not directly related to or limited to an increase in size or maturity in function. In examining reproduction, we have

already seen that reproduction presupposes this particular kind of interrelationship between parts of a living being. After that, we also saw that the complementary interdependency between parts of a living being is a necessary condition only to the extent that it can secure the active power that the living being has to assimilate vital energy from its surroundings. That is to say, both of them are only possible in connection with metabolism. Growth, different from yet related to metabolism, is characterized by maturation and increase in size (the enlargement of the whole, some organs, or the increase in the number of organs). In the botanical realm, living plants exhibit continuous growth: always increasing in size, or adding new organisms such as leaves and stems. These changes are only possible with metabolism as metabolism converts nutrients into energy and building blocks that are necessary for growth. More importantly, without metabolism there will be no organic individual to grow.<sup>45</sup> However, the association between metabolism and growth is not uniform in all life forms. Living cells and animals are examples that demonstrate this disconnection. In the animal kingdom, growth follows a predetermined scheme: animals only grow through a certain period of time, in size and in maturity. Almost all adult mammals cease to grow when they reach full maturity. However, metabolism continues to maintain body functions and repair damage. In the case of unicellular organisms, there is no traditional growth as we observe in multicellular organisms, such as animals and plants. Instead of increasing in size, unicellular beings replicate by dividing into new cells. Moreover, cells in mature tissues (like muscle cells) may not grow or divide in their non-dividing state. However,

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<sup>45</sup> This is common knowledge that we can find in general textbooks.

metabolism is still required to maintain their functions.<sup>46</sup> Therefore, growth, in the sense of increase in size and level of maturity, is not a sufficient condition for being organic.<sup>47</sup>

From comparing organic and inorganic systems, we already know that all three of the processes Kant is concerned with are sufficient to account for life, e.g., having any of them guarantees the object is different from an inorganic being. Growth and the reciprocal dependency among parts of organic individuals are necessary for life only to a certain extent or under certain conditions. Does growth also depend on a particular condition to be present in life? Growth in Kant's discussion is more than an increase in size and maturity in function; it is the active power in the system that allows it to interact with the surroundings to maintain this power. Is this a necessary condition for being alive?

On the one hand, it is not necessary for a living being to undergo constant interactions with its surroundings. Hibernation is an example demonstrating this point. However, it is not a legitimate example in the sense that animals under hibernation still breathe continuously, although unconsciously. The metabolism rate is indeed lower in hibernation; however, it is not a stable natural state: air is still required to maintain the metabolism which supports the function of the whole system. The metabolism is still ongoing in hibernation – only it is powered by those pre-stored energies. Before hibernation, animals need to intake extra food to prepare for the lack of material interaction with the environment during the hibernation. Seeds, which are stored for a long time, often shrink in size because of the use of energy stored in their endosperm or

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<sup>46</sup> Alberts et al. 2002

<sup>47</sup> There are also studies that suggest that certain tropical plants may cease trunk growth upon maturity while metabolism continues for maintenance and repair (Thomas 2011).

cotyledon. Appropriate examples of living beings not interacting with their surroundings would be during periods when an animal is holding its breath, a seed is waiting to be planted, or a piece of branch awaits being grafted. Holding and waiting in the scenarios suggest that the non-interaction situation is temporary. It is different from a dead animal that cannot and does not need to breathe, or a dead seed that can no longer be awakened by appropriate surrounding conditions. It is clear that ongoing interactions with the environment are not necessary for being alive. The key to this concept of growth as an identifying process for life is maintaining the potential of the ability to have such interaction. Animals can intentionally stop their interaction with their surroundings for a certain period of time and intentionally resume it when needed as long as the metabolism is untouched. Plants do not have such capacity. Plants will passively start to interact with their surroundings when appropriate conditions are met; when it is warm and humid, the growing process awakens passively. It is the active power of the plants which engage in the interaction, but they have no choice other than to start it when conditions permit. Now we can see that the ability of an organism to exchange materials with the environment and to assimilate them to maintain itself is the sufficient and necessary condition for being alive. It may or may not include increasing in size and the level of maturity, which is growth. Self maintenance includes actualizing a full functional development and fixing damages.

### 2.3 Conclusion

To sum up, all the three non-mechanical processes Kant identified from his experience of trees are sufficient conditions for being alive. The necessity of these three

processes for being alive stems from the systematic interactions between the parts within the organisms which can maintain a particular interaction with the world outside them. As the necessary and sufficient condition for being alive, it can be taken as a definition of life. However, the validity of this definition is compromised by Kant's epistemological system. From modern science's understanding of chemistry and molecular science, we know that there are more aspects of life that we can know in a necessary way. Those studies, which were not available in Kant's time, distinguish matters in a necessary way and can explain the particular chemical interactions between matters in an objective way. Those deeper understanding of the inorganic interactions is necessary for our understanding of the complementary relationships between organs in living beings as Kant discussed. Compared with the mechanical system in Kant's approach, which does not take into account what the relevant materials are, the unity formed in a living system is more intensive and determinative. This unity is formed, and structured according to the nature of the differentiated matters involved: this is different from a mechanical system in which undifferentiated matter is held together according to gravitational forces, certain mechanical forces and inertia.

Kant's theory of life takes a big step forward from Aristotle, by introducing a new causal relationship, internal teleology whose self-organizing process is similar yet also different from the Aristotelian concept of end. As Aristotle does not have a concept of self-causing, he cannot fully account for how living beings function. Moreover, although Aristotle's conception of the end can distinguish artifacts and natural products, he is unable to distinguish living from non-living natural entities. Kant discovers the key characteristics of life and accounts for them by means of internal teleology and self-

causing. His theory can account for the difference between organic and inorganic nature. However, the explanation for this difference cannot be accounted for by his mechanistic understanding of nature.

## CHAPTER THREE

### CHEMICAL PROCESSES AS A PRECONDITION FOR LIFE

Kant has properly identified three fundamental life processes which are not reducible to mechanistic ones because of the internal teleology they exhibit. The three fundamental life processes are organic unity, metabolism, and reproduction. Kant, however, limits our knowledge of nature to the realm of mechanism, which concerns undifferentiated matter in motion. As a result, he “bans” us from being able to have genuine knowledge of life. Hegel does not deny the Kantian understanding of life, but Hegel extends the knowledge of nature beyond mechanism to include physical processes. In physics, matters are differentiated by exhibiting so-called secondary properties involving electromagnetic polarity. Hegel’s conception of physics covers the whole of inorganic nature beyond Kant’s mechanics of matter in motion, accounting for the states of matter, differences of elasticity and cohesion, sound, heat, light, magnetism, electricity, and chemical reactions. The objective determination of these physical realities provides us with knowledge of some of the necessary preconditions of the emergence of life. In order for life to arise and subsist, those conditions must exist in a certain astrophysical environment. This environment, and the physical processes mentioned above, form an unified biosphere. This biosphere provides all the enabling preconditions for life to arise and subsist. The objectivity of these life-enabling physical processes is discussed in this chapter, whereas the objectivity of the biosphere will be the topic for Chapter 5.

Knowledge of the electromagnetic polarity of positive and negative charges in physics allows us to understand the qualitative transformations of inorganic materials that comprise chemical processes. Understanding the qualitative physical transformation of inorganic materials is essential for understanding life.<sup>48</sup> Hegel's objective understanding of these processes can lead us to objectively account for the three identifying characteristics of life. He encapsulates this by observing that "if the products of the chemical process spontaneously renewed their activities, they would be Life" (Hegel and Miller 2004, page 269). That is to say, biological processes essentially integrate groups of chemical reactions into a self-renewing complex with new features transcending those of ordinary chemical processes. Hegel shows us how life, with its three irreducible fundamental functions, can be composed of inorganic processes and in what sense chemical processes allow biological entities to emerge in nature.

Hegel's inquiry into life proceeds upon the determination of chemical processes. In this chapter, we will examine Hegel's understanding of chemistry and how it involves physical processes extending beyond mechanics. We will also see how electromagnetism in particular lays the ground for the determination of chemistry. It will become clear that although Hegel's understanding of nature was limited by the scientific knowledge of his time, contemporary theories of chemistry are generally in line with Hegel's conception of chemical processes.

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<sup>48</sup> More details of why chemistry is a necessity for the phenomenon of life will be discussed in the next chapter.

### 3.1 Hegel on Chemical Processes

Hegel describes chemical processes as the “unity of magnetism and electricity” (Hegel and Miller 2004, page 232). That is to say, chemistry is constituted out of magnetism and electricity. To understand Hegel’s account of chemical processes, we therefore need to address how magnetism and electricity make chemistry possible without themselves constituting chemical reactions.

#### 3.1.1 The Determination of Electromagnetism – Shape

Following upon the determination of mechanistic processes in nature, where things are undifferentiated, Hegel determines how materials are differentiated by their shape. Undifferentiated materials individuate themselves by their “resistance to outside force” (Hegel and Miller 2004, page 160) – by maintaining the external “spatial togetherness of matter” when force acts on them. Here, Hegel explains materials are differentiated by a “specific kind of inner connectedness” (Hegel and Miller 2004, page 160). This inner connectedness is shaped. It is a qualitative determination of how a material’s parts stay together in relation to each other.

*Shape* in this context is not generated just by gravity or by the mechanical impact of other bodies. Shape here involves a specific type of physical spatial configuration that comprises a self-subsistent physical form, be it organic or inorganic.<sup>49</sup> This configuration entails physical properties such as heat and light transmittance, taste, smell and hardness. Through this physical configuration, materials are qualitatively differentiated from each other.

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<sup>49</sup> Winfield 2017, page 317

Shape manifests itself in a material by how strongly it holds itself together and how it can be modified by external influences. Hegel points out that there are two types of shapelessness. One is extreme brittleness, and the other is liquidity. Their particular shape is an inner shapelessness<sup>50</sup>. Pure brittleness is the extreme of the punctiform principle where each point manifests no relationship with other points; whereas fluid matter is the extreme of the spherical shape in which points are held together regardless of any dimensional differences in space<sup>51</sup>. Between these two extremes materials maintain a determinant shape.

### 3.1.2 Magnetism

Moving from the extreme of pure brittleness, physical points start to be in relationship with each other in the most simple way – forming a line. In a line, there are two sensible opposing ends and a middle. The two ends are two poles with “no mechanical reality but only an ideal one” (Hegel and Miller 2004, page 163). They do not have mechanical reality because each, by itself, is undifferentiated from the other – this is their mechanical reality. The poles only have their identities as opposing each other by existing in a unity. This is the determining property of magnetism.<sup>52</sup> The poles have meaning only by connecting to each other in the same unity.<sup>53</sup> In magnetism, a pole cannot be separated from the unity to have its own independent mechanical

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<sup>50</sup> Hegel and Miller 2004, page 257

<sup>51</sup> In a spherical body, the body extends in all dimensions indifferently.

<sup>52</sup> “They have maintained an existence solely in unity; polarity is the relation only of such moments. Apart from the determination here explicated, magnetism has no further special property”.

<sup>53</sup> “The poles are the sensible existent end of a real line, but as poles, they have no sensible, mechanical reality but an ideal one, and are absolutely inseparable” (Hegel and Miller 2004, page 163).

existence as it can only exist in opposition to the other pole in the same unity.<sup>54</sup> In addition, there is no way to distinguish the poles by any physical properties other than their relation to each other. The self-relating identity of magnetism has its determination through an ideal relation, whose poles have no sensible difference. The magnetic substance may thus be physically uniform in all other respects.

Since magnetism is a formal polar unity, the materials which manifest it do not affect the characteristics of magnetism itself. That is to say, magnetism in iron has the same characteristic as magnetism in other minerals, because magnetism only manifests itself through dynamic spatial relationships. Alterations of magnetism cannot be perceived in the body itself, but can only be perceived in the change of its spatiotemporal determination. That is why Hegel suggests “the alteration of magnetism can only be a movement for movement is precisely this alteration in time of what is spatial” (Hegel and Miller 2004, page 169). A body shows its magnetic characteristics, by how it moves, when placed in the magnetic field of another body. This exhibits the fundamental rule of magnetism, that the same poles repel each other, and the opposite poles attract each other.

Magnetism’s unity of binary opposition<sup>55</sup> is not a mechanical or a sensory property. It operates above and beyond the gravitational attraction of bodies. Magnetism does not alter the constitution of materials. When something is magnetized, it does not undergo any further change. Being magnetized only gives the object the ability to exhibit a specific magnetic force by exerting attraction or repulsion of other magnetically

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<sup>54</sup> Hegel and Miller 2004, page 164

<sup>55</sup> Hegel and Miller 2004, page 221

charged substances. However, this kind of magnetic interaction will not change the objects' physical properties and distribution of particles. Being magnetized only changes the position of electrical particles within materials. The magnetic force makes redistribution of electrons possible when certain external conditions are provided, i.e., difference in electrical potential or friction with other materials. One object can be electrically charged by losing or gaining electrons through physical relationships such as rubbing. Magnetism is essential in electricity because "adding" electrons to an object does not put one electron in physical contact with the object – the new electrons can only be a part of the object's overall electrical field when they are integrated in its current structure of electrons by interacting with their magnetic field. Magnetism provides the basis for electricity because electricity is caused by the redistribution of electrons which can only be realized by magnetic polarity. Being electrified with static electricity, or having current passing through, both involve changes in the object's structure of electrons, whereas being magnetized does not cause such concrete change in the structure of the object. In electrical current, a non-neutral distribution of electrons is passing through the object. This transmission continues as voltage is retained. The physical structure of the conducting substance, through which the electricity travels, stays unchanged after the current passes through.

Hegel makes it clear that the existence of electricity and chemistry depends on the foundation magnetism provides.<sup>56</sup> Magnetism has an ideal polarity that can further individualize matter to a more real opposition. This occurs when the opposition of poles

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<sup>56</sup> "[M]agnetism is the principle of form, and electricity and chemical process are merely other forms of this principle" (Hegel and Miller 2004, page 171). And "all electrical action is magnetism: magnetism is the fundamental force which produces different terms, which likewise keeps them apart while also keeping them absolutely connected. This, of course, is what happens in both the electrical and the chemical processes, only more concretely than in magnetism (Hegel and Miller 2004, page 172).

gains individualized physical existence in electricity. Here, we have a physical process involving positively and negatively charged bodies.

### 3.1.3 Electricity

There are two opposing polarities in electricity as a result of the two magnetic polarities gaining real existence by differentiating themselves into separate extremes. As they gain individualized existences, they do not need to be in unity with an opposing polarity to show their own identities. It is possible to have an electrically charged body without reference to an oppositely charged body. Hegel's theory of electricity is developed from his understanding of magnetism. Lacking knowledge of atomic theories, he claims there is no inherent identity built into the positivity or the negativity. When two charged bodies are presented, if they attract each other, they have opposite charges. While if they repel, they have similar charges. Back to Hegel's time, if a charged body is not in such a relation, it cannot be identified as positively charged or negatively charged.<sup>57</sup> With contemporary atomic theory, we understand charged bodies to have an intrinsic charged identity based on their atomic structure. We consider electrons to have negative charge, so atoms with more electrons than protons are negatively charged, whereas those with fewer electrons are positively charged. In this sense, each charged body has an electrical identity without reference to other charged bodies. Their behaviors in the relationship with each other do not otherwise determine their physical

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<sup>57</sup> The electron was first identified by J.J. Thomson in 1897, during experiments with cathode ray tubes. Hegel dies before this.

identity, just as Hegel suggested.<sup>58</sup> This makes electrical phenomena different from other developments of physical individuality in that “electricity does not appear to be rooted in the independent shape of the bodies it involves” (Winfield 2017, page 356). Electrical characteristics are indifferent to the shape of materials with electricity – electrical changes are superficial changes that occur to and between materials. The same electrical phenomenon can occur in different materials, with different physical shapes – a plastic ball and a metal ball can equally be charged and transmit current. The only thing is that their physical differences may make the process of charging quite different – their different atomic shapes would involve different abilities to hold electrons.

Electricity is also conditioned by external influences. A body, Hegel notes, cannot change its electrical state without being affected by others.<sup>59</sup> Although it is common to use specific materials, for example plastic and fur, to rub against each other to produce static electricity, Hegel maintains that “electricity makes an appearance wherever two bodies come into contact, especially when they are rubbed” (Hegel and Miller 2004, page 224). Electricity is a general phenomenon for which “contact is the condition” (Hegel and Miller 2004, page 225). Unlike magnetism, electricity actualizes the polar opposition in itself by transferring one of the opposing poles to something other than itself. This transformation requires contact. Without any contact, the opposition would remain within the same body – the opposition would still be potential as in magnetism. Therefore, to make an uncharged body become charged requires the existence of

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<sup>58</sup> However, Hegel does notice that when rubbing two materials, how they are charged is not randomly assigned. Some of them are likely to be positively charged. He cannot have an objective understanding of the phenomenon. With our understanding of atomic structures, we now know that some materials are more likely to be positively charged and others are more likely to be negatively charged depending on their ability to hold onto their own electrons.

<sup>59</sup> Hegel and Miller 2004, page 221

another body and particular contact between them. Because of this, electricity depends upon external conditions – a body cannot acquire additional electrons without any contact with other things. However, contact is not sufficient for changing the electrical state of a body. Hegel suggests that every pressure, every blow can produce electrical tension between the bodies in contact; the only problem is that with certain materials, the electricity is too weak to be detected. It is important to be aware of Hegel's emphasis on pressure. He does not suggest that the wind blowing can always produce electricity – it can create electrical tension but the opposition may not fully separate electrical bodies. Also the word “blow” implies a pressure on the contacting surface. Therefore, pressure is essential for contact. It also tells us that, even if we rub quite similar glass tubes as Hegel suggests, one would become negatively charged, and the other positively charged.<sup>60</sup> It is essential that there is a certain pressure on the contacting surface – they are not merely contiguous. In electricity, unlike in magnetism, the impact on the material, in electricity, goes beneath the surface. It is important to notice that electrical processes are not yet the dissolution of shape itself – it is only a superficial process that does not yet transform the material as in chemical processes. Electrical contact is sufficient for materials to transmit charges between them, but is not sufficient for chemical reactions to occur.<sup>61</sup> Such processes do not change any physical features of the objects, e.g., transparency, taste, hardness and so on. However, the electrical process is less superficial than sound. Sound is a physical vibration produced

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<sup>60</sup> Hegel and Miller 2004, page 221

<sup>61</sup> This difference is clear in the framework of atomic theories. Chemical reactions consist in the formation of molecules, by combining atoms together or breaking apart existing molecules, but not alterations of atoms. Changing one atom to a different atom is not a chemical process, it is in the realm of nuclear physics. Electricity touches neither of these processes – it only moves electrons from one atom/molecule to another.

by some impact. In electricity, rubbing can produce electricity, with the structure of the surfaces determining which one will be positively charged, and which will be negatively charged.<sup>62</sup>

There is no inherent identity built into the positive or the negative charges, the core of electrical phenomena is their binary opposition.<sup>63</sup> The bipolarity exhibits itself as a special movement – identical charges repel and opposite charges attract. So electrical phenomena are superficial effects that do not change the shape or the qualitative features of the materials – they come to play “in so far as positive and negative electricity are kept apart from each other in different bodies” (Hegel and Miller 2004, page 224); yet they are deeper than external mechanical influences, such as sound, in that oppositely charged bodies are genuinely differentiated.<sup>64</sup>

According to modern physics, all atoms have positively charged nuclei and negatively charged electrons moving around the nucleus. An atom has an aggregated charge determined by the number of positively charged nuclear particles and of electrons. It requires tremendous energy to take away or add protons to an atom, whereas it is easy for an atom to gain or lose electrons, or share electrons with other atoms. So any interactions that transfer electrons between atoms can make atoms lose their aggregate neutral charge and become positively or negatively charged. One atom, with a total neutral charge, can acquire an aggregate electrical charge through some

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<sup>62</sup> Hegel and Miller 2004, page 224-6

<sup>63</sup> Hegel was aware of the opposition, but as he had no knowledge of electrons. Therefore, he was unable to distinguish the essential difference between positivity and negativity. The electron was first identified by J.J. Thomson in 1897, during experiments with cathode ray tubes.

<sup>64</sup> Hegel and Miller 2004, page 324

particular physical contact that alters the distribution of electrons.<sup>65</sup> The redistribution is powered by the electromagnetic force which attracts oppositely charged materials, and repels similarly charged material. The friction between two materials changes the distribution of their electrons through physical pressure. This deformation (reshaping) temporarily polarizes the atoms in question. The positive body will attract electrons from the other material. Friction generates heat energy which increases the kinetic energy of the electrons on the shell of the atoms. The increase in kinetic energy makes the electrons move faster. As a result, they can move further away from the core of the atoms. Therefore, the atom has less attractive force to keep the electrons moving around itself. These two factors work together to make the gaining and losing of electrons both theoretically and practically possible. Although changing the number of particles in the nucleus can also change the aggregate charge of an atom, these changes belong to a different process, that of nuclear reaction.

When static electricity builds up enough on one body to overcome resistance to transmission, it will discharge to reduce the electrical potential differences between the charged body and other bodies. Lightning bolts are a natural phenomenon exhibiting this. Electric charge is built up in the clouds. When it reaches a certain amount, it can overcome the electrical resistance of the air between the cloud and the ground to produce a current while emitting energy in the form of light and sound.

Current involves transmission of electrically charged particles from one material to another. This can take place in terms of a build-up in static electricity, which then releases into a single transmission or can take the form of a continuous current. Such

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<sup>65</sup> As discussed earlier, it must be contact with pressure on the contacting surfaces.

transmissions are driven by the different electrical potentials, i.e., voltage. In a battery, for example, a kind of potentiality is built into each of its poles, this difference will be degraded by the transmission of charged particles through conductors between the two poles. The physical structure of the conductor stays unchanged after the current passes through. However, particles in the conductor are in a charged state when the current passes through because as the charged particle passes through the conductor, particles in the conductor change the electrical neutral states of the particles in the conductor. However, the particles of the conductor are unchanged after the current passes through because each of them passes the change it receives to its neighboring particles. The thing through which electricity passes “is indifferent, independent existences which hold to themselves even in being changed; the very thing which characterizes electricity” (Hegel and Miller 2004, page 252). Particles of the conductor are changed only in the sense that when the current passes through, each part of the conducting material will be temporarily charged as the current passes through it in one direction. The conducting medium will not be charged in any way after the current passes. Its shape, which is the identifying structure of the material, is untouched.

Hegel demonstrates his understanding of electrical current under the title of *Combinations* in chemical processes because, he points out, the transferring of charged states changes the chemical configurations of the materials the changed state passes through (Hegel and Miller 2004, page 250 ). Insisting on the differences between chemical and electrical process, even Hegel agrees that the “the more specific result of the galvanic process is the oxide, a metal posited with a real difference” (Hegel and Miller page 255–256). Therefore, his discussion of current, an electrical phenomenon, is

in the chapter about chemical processes under the name, *Galvanism*. Hegel points out that there are people who mistakenly attribute chemical action solely to electricity, because electric current can induce chemical reactions.<sup>66</sup> However, neither static electricity nor current would change the chemical configuration of their bearer — electricity can trigger those changes.

Like the passage of sound — electric current only exists in its passing away. To explain why electricity is a superficial phenomenon which is essentially different from chemical processes, Hegel draws our attention to the analogy between sound and electricity.<sup>67</sup> Both of these phenomena involve two factors that maintain their identities through these physical processes. Sound is essentially a physical vibration and oscillation which exists in its passing away. Sound can change the physical character of some materials, yet it never involves chemical processes as sound cannot affect the constitution of materials. The reason is that the vibration of sound affects only the mechanical shape of material. The mechanical force, which holds the substance to its physical shape, will, by resisting external deformational force, counteract this influence from sound. When the force is not strong enough to hold, the original shape breaks. A common example is that sound at a certain pitch can shatter a glass.<sup>68</sup> The glasses are not transformed into other materials, but their physical shape is changed. Two objects are required to create the sound and some medium is required for the sound to propagate. Their physical characters dictate how they vibrate when they are physically

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<sup>66</sup> Hegel and Miller 2004, page 255

<sup>67</sup> Hegel and Miller 2004, page 256

<sup>68</sup> Even though this wave is outside the range of human hearing, it is still a sound phenomenon because it is a wave.

in contact with each other and how they propagate their vibrations.<sup>69</sup> Like sound, electric current requires two objects.<sup>70</sup> Whereas in sound, the two objects have no polar opposition. The two objects must have a charge opposition for electricity to be produced between them.

With electricity both bodies are differently disposed to each other, so that the exciting body...enters into the difference; in sound, on the other hand, only one of the bodies sounds, or if both sound, the sounding of each is indifferent to the other's. (Hegel and Miller 2004, page 306)

However, in electricity, they cannot both be charged with the same charges – they must be opposite. Then they transmit electromagnetic charges between them and, therefore, alter their electrical polarity.

### 3.2 The Basic Determination of Chemical Processes

Hegel did not have knowledge of atomic structures to account for chemical reactions;<sup>71</sup> yet he has a clear idea of how chemical reactions involve electromagnetic polarity, but constitute processes that are irreducible to electrical and magnetical ones.

In mechanical processes all objects figure as undifferentiated matter, distinguished only by their extension and mass. In mechanical process, objects change

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<sup>69</sup> Two iron bricks can make a sound which is very different from what two piles of cotton make. The way they are able to vibrate, along with several external factors, affect what sound they can make and how far that sound can propagate.

<sup>70</sup> As discussed earlier, it requires two objects to give the internal oppositions a genuine existence.

<sup>71</sup> Contemporary scientists use charges in the distribution of electrons to identify the breaking or formation of chemical bonds. We will address this in detail after having laid out Hegel's discussion of them.

their size, density, or velocity, yet remain the same in other respects. The reason is that mechanical processes do not alter the qualitative structure of any material. Without such changes, materials keep their original physical characters. For example, when an iron bar undergoes mechanical changes, it may change its location in space, its velocity, size, geometric shape, or density, yet it is still iron. It will not become iron oxide or some other element, i.e, manganese or cobalt.<sup>72</sup>

The essential difference between a chemical process and those superficial physical ones is that chemical change involves changes in the special structural affinities of the particular electromagnetic configurations of different reactants. Electromagnetic forces decide how the positive and negative charges are distributed. The distribution occurs according to the same electromagnetic rules governing electricity and magnetism, yet yields different chemical reactions because the materials have different numbers of positive charges and negative charges. This electromagnetic configuration of a material affects its disposition to get into a chemical reaction. This disposition, which is innate to the material, is its chemical affinity.<sup>73</sup> Each chemical has its specific affinity which determines its susceptibility to enter into certain chemical reactions. The reaction between chemicals alters their specific electromagnetic configurations and gives rise to materials with different electromagnetic structures, which have different chemical affinities from there of the materials from which the reaction proceeded. This change is the identifying character of chemical reactions. The

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<sup>72</sup> These are the two elements next to iron in the periodic table. They have one less and one more proton than iron, respectively.

<sup>73</sup> It is an impulse that everything has to itself (Hegel and Miller 2004, page 236).

fate of a material in chemical transformations depends upon the relation of electromagnetic forces. Some materials are chemically inert and do not participate in any chemical reactions. Others are reactive in relation to specific chemicals. One substance will interact chemically with another substance because of how they are polarized. Their polarization is rooted in the uneven distribution of positive and negative charges. However, it is important that the chemicals are in a situation allowing the electromagnetic forces to work upon them. For example, when two chemicals are too far apart from each other, they are not affected by the electromagnetic forces wielded by one another. So their qualitative structure is not affected.<sup>74</sup> Whether or not a material will undergo a specific kind of chemical transformation, and how fast it will react, depend upon its own qualitative structure, i.e., chemical affinity, and certain external conditions.

### 3.2.1 Two Essential Characteristics of Chemical Reactions

Winfield (2017) points out that two important aspects of chemical reactions, discussed by Hegel, are essential for our understanding of how chemistry differentiates itself from physics and from biology. On the one hand, the material (s) resulting from a chemical reaction are different from those with which it began; On the other hand, all chemical reactions are finite in that they depend on external conditions. Organic process comes into being when those aspects are overcome.

Hegel points out that in chemical processes, "[t]he beginning and end of the process are separate and distinct" (Hegel and Miller 2004, page 269). On the one hand, the materials resulting from a chemical process are different from those at its beginning.

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<sup>74</sup> Details about how ALL chemical reactions are subject to external conditions will be discussed in the next section.

If this is not the case, it is not a chemical reaction. On the other hand, the ambient conditions in which the reaction takes place, such as temperature and pressure, can be changed as the reaction happens. For example, the combustion of gasoline is an exothermic (heat-releasing) reaction. In this reaction, gasoline ( $C_8H_{18}$ ) reacts with oxygen ( $O_2$ ), producing carbon dioxide ( $CO_2$ ), water ( $H_2O$ ), and releasing a lot of heat. The material before the reactions, gasoline, is different from the products, water and carbon dioxide. This change is inherent in all chemical reactions because chemical reactions are defined by the transformation of materials. The change of temperature in the surroundings is unavoidable because the change is the result of the breaking or formation of chemical bonds: such processes absorb energy from the surroundings or release energy to them. Chemicals are held in their particular structure by electromagnetic force. Each material has a certain number of positively charged and negatively charged constituents. The way in which they are structured follows the electromagnetism laws of charged bodies – the same repel and the opposite attract. Those charged particles will settle into a particular structure that balances the repelling and attracting forces. These forces have to be resisted to break the chemical apart. In this case, the chemical needs to absorb energy to overcome this force. When separate chemicals are joined together, these changes of molecular structure will alter the temperature of the surroundings.

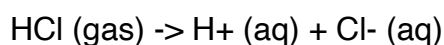
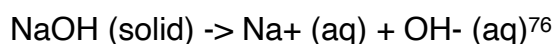
The second feature of chemical processes is that they are conditional on something in their environment. An individual chemical reaction is never self-activated. Chemical reactions may either combine separated chemicals into one or break one chemical apart. The former requires moving materials close enough to combine them.

The latter requires energy from the outside to break whatever forces hold the chemical structure in place. The chemical itself does not have the ability to break these electromagnetic forces in itself for they keep it in a stable unity. Therefore, some external factors must intervene to break the structure of the chemical. As Winfield (2017) notes “these precipitating requirements are not supplied by the chemicals themselves that undergo chemical transformations. So conditioned, chemical process is finite” (Winfield 2017, page 20). It is finite in the sense that every chemical reaction always depends on the external environment – chemicals do not have the ability to kindle chemical interactions themselves. As with sound and electricity, Hegel points out external conditions are required to engender the interaction.<sup>75</sup> At the very least, external forces must bring chemicals not just into contact, such as a pressureless touch of their contacting surfaces, but into inter-penetration. With sound, two objects cannot resound if they do not impact on one another. The factor which can facilitate the necessary interaction is external to the interacting objects. Sound can be made when a rock falls to the ground, or two magnetic bars crash into each other. A rock’s falling requires the removal of whatever has been holding it away from the ground; if there were no such hindrance, the rock would already be on the ground. Also, sufficient gravitational force is required to make the impact of the rock and the ground produce reverberations. On a much smaller planet the gravitational force may not be able to pull the rock hard enough to make sound when they are in touch. Moreover, to have sound, there must be a medium to transmit the sound, i.e., water or air.

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<sup>75</sup> Hegel and Miller 2004, page 221

Winfield (2017) points out chemical reactions require a thoroughgoing contact that can overcome the surface resistance presented by the external shape of each material. Being dissolved in a solvent is one way in which shape gets modified to permit the thoroughgoing contact necessary for chemical reaction. The neutralization between sodium hydroxide (NaOH) and hydrochloric acid (HCl) illustrates this. In order for this reaction to occur, both reactants must be dissolved in a solvent – water in this case. Solid NaOH and gaseous HCl, in their natural states, cannot react with each other even when they are in close physical contact. Dissolving them in water dissociates them into their respective ions:



At this point, these two reactants are in the required thoroughgoing contact. Through the change in the shape of each factor, the aqueous ions can come into sufficiently close contact to react with each other by forming new chemical bonds. The solvent serves as a medium for reactions to move, mix and interact; solvents are not directly involved in the reaction, nor do they alter the reactants or the products.

There are other physical interventions that can create thoroughgoing contact between reactants, e.g., strong physical impacts, high temperature, high pressure and sound waves with a desired frequency. The resulting interpenetration contact “allows the chemical affinities of all basic components of each material to come into play” (Winfield 2017, page 378).

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<sup>76</sup> The "aq" notation in the equations indicates that the ions are present in an aqueous (water) solution.

Apart from proximity, there are other external conditions that affect chemical changes. For example, a decomposition reaction does not require any “proximity” but depends upon external conditions such as the addition of energy or the presence of catalysis. Water electrolysis is a noteworthy example. An electric current passed through water can cause the chemical decomposition of water ( $H_2O$ ) into hydrogen gas ( $H_2$ ) and oxygen gas ( $O_2$ ). Liquid water is stable under Earth's natural conditions and has been for most of geological history. As the current passes through water, water molecules are polarized because the strong electromagnetic force transmitted by the current will rearrange the charged materials in water. Water will be further polarized insofar as the injection of energy, brought in by the current, overcomes the forces which hold water particles together, making the positively charged materials move towards the negative pole of the current, and the negatively charged move towards the positive pole. Here, hydrogen atoms and oxygen atoms are separated and gather at the two poles respectively. Because of the basic electromagnetic rule: same attract and opposites repel, hydrogen gas will be produced at the negative pole of the current, and oxygen gas will be produced at the positive end. External energy and a strong polarized environment are required to break apart the water molecules and produce the separated gasses. This chemical process is still finite in that it is conditioned by the addition of electrical current – an external factor in respect to the reactants.

In some reactions, reactants can only chemically interact with help from catalysis. Hegel does not have any specific knowledge of catalysis, but he recognizes that a mediation factor can facilitate chemical reactions.<sup>77</sup> However, Hegel's understanding of

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<sup>77</sup> Hegel and Miller 2004, page 236

such a middle term is not exactly the same as the contemporary understanding of catalysis.<sup>78</sup> According to contemporary chemistry, a catalyst can only increase the speed of chemical reactions. The catalyst itself stays unchanged at the end of chemical reactions, but increases the rate of chemical reactions by providing an alternative reaction pathway. When two chemicals react with each other through the presence of a third medium, this is not a reaction, but two reactions happen one after another. The third medium is a chemical reactant in the same way as the other chemicals – it is not a catalyst, although it is a “third party” for the targeted reaction. The reason some reactions seem impossible without catalysis is that they happen at an extremely slow rate under natural conditions, mainly because of the significant amount of energy they require. Catalysts provide an alternative pathway that requires less energy.<sup>79</sup>

Ammonium hydroxide ( $\text{NH}_4\text{OH}$ ) is a stable alkaline in its natural condition. Its decomposition can barely be observed under ordinary terrestrial circumstances. A suitable catalyst, such as sodium hydroxide ( $\text{NaOH}$ ), can facilitate the reaction by lowering the required activation. Then, ammonium hydroxide can decompose into ammonia gas ( $\text{NH}_3$ ) and water ( $\text{H}_2\text{O}$ ) at a reasonable rate.

All chemical reactions are finite in that they only happen under certain external conditions. There is no literal spontaneity in chemical reactions because chemical reactions are not self-activating. That the products of chemical reactions are different from the reactants confirms this inability to be self-activating. A chemical reaction is

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<sup>78</sup> Hegel and Miller 2004, page 236

<sup>79</sup> When it is almost impossible to climb over a mountain (within one's life span), they can always go around it if a pathway is provided.

inherently unable to recreate the material conditions it begins from through the chemical process itself.

There are two things we need to bear in mind concerning the environmental conditions for chemical reactions. On the one hand, although some chemical reactions occur naturally, they still depend upon external conditions. It just happens to be that natural conditions on Earth enable them to occur. The pressure, temperature, and composition of the Earth's atmosphere provides common terrestrial enabling conditions. For example, iron rusts spontaneously on Earth through an oxidation reaction between iron and Oxygen producing iron (III) hydroxide ( $\text{Fe}(\text{OH})_3$ ). The same reaction is not likely to happen on Mars, although there is iron on Mars. This reaction requires both oxygen and water. Although there is oxygen on Mars, its much thinner atmosphere contains only 0.2% oxygen. This is far less than the 21% proportion of oxygen in Earth's atmosphere. For rusting to occur, liquid water is needed to function as a solvent facilitating the oxidation between Oxygen and Ferrum. Water on Mars is not only extremely scarce, but can only exist, if at all, in a solid states. Earth happens to have temperature and pressure allowing for abundant liquid water.

On the other hand, chemical reactions can affect the reaction-friendly environment so that these reactions cannot continue. For example, an endothermic reaction reduces the temperature of the surrounding area. If the environment is closed, the temperature may drop so that the reactants cannot obtain enough energy to be chemically activated. Thus, when liquid water freezes, certain reactions, such as the rusting of iron, can not occur anymore. There are also situations in which "proximity" is

taken away when reactants are depleted in the immediate environment.<sup>80</sup> Therefore, specific changes in the surroundings, caused by chemical processes, may remove the enabling condition, making it impossible for the same process to reoccur.

### 3.2.2 One Example Demonstrating the Differences

In Section 327 in his *Philosophy of Nature*, Hegel discusses how some alchemical transformations are not chemical processes. Winfield (2017) discusses why the productions of alloys are not chemical processes in order to clarify how Hegel differentiates chemical processes from other natural phenomena. Winfield focuses on the following three aspects to distinguish alloy formation from chemical reactions. First, the different materials that enter the process lack chemical affinity which consists in the tendency of different substances to react with each other. As we know from modern chemistry, such processes involve atoms with valence shells that gain or lose electrons to achieve a more stable configuration. For those atoms with filled shells, the process normally starts with breaking apart the shells to make them susceptible to chemical reactions. In either case, electromagnetic forces drive the reactions. Apparent transformations of substances without chemical affinity are merely thoroughgoing blends of materials. Materials maintain their chemical characteristics in a blend. The blending process, in comparison with chemical reactions, also exhibits a certain

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<sup>80</sup> These two particular situations, changing the temperature and exhausting the materials, are important in a later discussion about the possibility of self-renewing systems concerning the interaction between organic systems and their biosphere.

superficiality.<sup>81</sup> Second, those processes do not involve any intermediary catalyst.<sup>82</sup> Catalysts facilitate chemical reactions by interacting with the reactants on a deep level, namely, by affecting the shape of the chemical. Third, some properties of the original ingredients are preserved in the “new” material produced in this process.<sup>83</sup> Although the process of making alloys creates some new characteristics in the newly formed materials, no genuine chemical transformation is involved. Genuine chemical reactions include breaking existing bonds and forming new bonds between atoms, creating new materials by putting the original chemicals through chemical reactions. In such cases, the original materials will no longer exist after the reaction— materials that go through chemical processes will be transformed to different materials. However, in the case of alloys, we can still find the original materials in the final products – each of the two materials maintains its chemical identity through the processes. Their physical configuration is untouched. Admittedly alloys have new properties that the original materials do not exhibit, yet those are not changes in chemical bonds and chemical properties. Producing an alloy is similar to mixing two boxes of Play-Dough thoroughly to make Play-Dough of a different color, or mixing a box of Play-Dough and a box of sand to make a new material with new properties. It appears that the original parts cannot be identified in the product; but they are still chemically separated since they do not form new molecules.

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<sup>81</sup> Earlier in this chapter, we talked about how the phenomenon of sound and electricity exhibit superficial alterations compared with genuine physical changes.

<sup>82</sup> In Hegel’s time, there was no clear knowledge of catalysts. However, he was aware of the fact that certain conditions are required for the reactions to occur. The idea that certain materials can mediate creation reactions can be considered as an idea of catalysis. It will be examined after the current discussion.

<sup>83</sup> Winfield 2017, page 371

### 3.2.3 Hegel's Classification of Chemical Processes

Chemical reactions are of two basic kinds, i.e., combination and disassociation.<sup>84</sup> Although Hegel is not aware of atomic and molecular structure, he recognizes that there can be only these two basic types of chemical reactions.<sup>85</sup> Combination involves combining two or more different chemicals into a new chemical, while dissociation divides a chemical into two or more chemicals. Insofar as chemical reactions involve breaking or forming bonds between different types of atoms, we know that each and every chemical reaction must consist in combination or dissociation. A single chemical reaction can never renew itself because to do so, a reaction must result in the chemicals that are the reactants from which the reaction starts. Neither combination nor dissociation can achieve that. Nonetheless these two types of reaction together provide the ingredients for an aggregation of chemical reactions that can renew itself. If there is only one kind of reaction, it will be impossible to return to the situation at the beginning. When two chemicals are chemically combined together to form a new chemical, the product cannot return to the original two chemicals through more combinations. Nor when a chemical is dissociated, the result differs from the starting point. With both combination and decomposition, however, it is possible for a group of chemical

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<sup>84</sup> Hegel and Miller, page 244 and page 264

<sup>85</sup> Here are some important developments in Chemistry of which Hegel had no knowledge: discovery of the periodic table (1869), atomic theory (early 19th century), quantum mechanics (early 20th century), polymers and plastics. Hegel's specific claims about natural science may be limited in detail, but not compromised in overall structure.

The situation is similar regarding the Darwinian theory of evolution. Darwin does not have much knowledge about genetics, which plays an essential role in the mechanism of inheritance shaping evolution. Because of this limitation, Darwin made some wrong claims about particular details of evolution. For example, Darwin does not know how changes can be passed down from generation to generation. He suggests that this happens through a process of "blending inheritance". The mistake was not spotted and corrected until the early 20th century (Mayr 1982). However, this issue does not compromise the power of Darwinian theory in shaping the developments in this field to this day.

reactions to return to its original material situation – the situation where the same reactants are presented. For example, two reactants A and B, can become AB after a combination, and AB can become A and B again after a decomposition. After the two reactions, the final products are A and B, which are the same as the reactants they started with. If there were only combination, or decomposition by itself, it would be impossible for a group of reactions to produce the same reactants they started with. However, this cannot decide whether or not other conditions can be the same as the starting point, such as if the reactants are at sufficient proximity, if the temperature and pressure is the same, and if the required catalysts are present. Being able to return to the original material situation makes it possible for a group of chemical reactions to renew itself. Whether or not a group of chemical reactions can kindle the next round of chemical reactions is still conditional on other external conditions.<sup>86</sup>

### 3.3 Contemporary Science on Chemical Processes

#### 3.3.1 The Change of Chemical Bonds as the Essence of Chemical Reactions

There was not much knowledge about chemical bonds in Hegel's time. The study of chemical bonds and the modern understanding of chemical reactions emerged in the late 19th and early 20th centuries. During this period, there were advances in the study of atomic theory which laid the foundation for our understanding of the formation and destruction of chemical bonds. Hegel's understanding of chemistry is not undermined by lack of this more recent knowledge. He insightfully notes how electromagnetism is the enabling condition for chemistry and how these two fields are fundamentally different.

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<sup>86</sup> The situations vary according to the pressure, humidity, presence of solvent and so on. More details are discussed in the following chapter about the transition from the inorganic world to the organic world.

According to our well established modern understanding of chemistry, chemical reactions consist in the formation and breaking of chemical bonds.<sup>87</sup> Chemical bonds are formed by electromagnetic forces that hold atoms together in a molecule. When two atoms/compounds are affected by each other's electromagnetic field, the electromagnetic stability is disturbed. In order to compensate for this disturbance, both need to rearrange their electrons to reach an overall more stable electron configuration. In some cases, each of the atoms donate an electron to form a group of electrons shared between them. Then each pulls the group towards itself as the electrons are negatively charged and the rest of the atom is overall positively charged. As each of them is holding onto the same electrons, it appears that they are connected by a bond. There are also situations where one atom snatches an electron from another one when they are affected by each other's electromagnetic force. The electron is attracted more by the other atom as it approaches, so that one of them will take the electron from the other. Then the atom with the extra electron becomes, overall, negatively charged while the other one becomes positively charged. The attractive force between the two oppositely charged atoms holds them together in a chemical bond.

In contemporary chemistry, there is a sophisticated understanding of chemical bonds and the mechanism of their formation. According to the view prevailing today, there are three major types of chemical bonds: ionic bonds, covalent bonds, and metallic bonds. The mechanism of forming and breaking of these bonds reveals how chemical reactions exclusively depend on electromagnetic forces. Electronegativity is a

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<sup>87</sup> This can also, to some extent, support Hegel's observation that there are only two types of chemical reaction: dissociation and combination. There are only two kinds of interaction that can happen between materials: holding two atoms and/or molecules together by forming new chemical bonds and separating a particle by breaking bonds.

measure of the ability of an atom to attract and hold electrons when joined with another atom to form a chemical bond. A chemical with higher electronegativity attracts electrons towards itself with a stronger force. The electronegativity of a chemical is inherent in its particular atomic or molecular configuration. For example, when one electron moves in an orbit far away from the positively charged nucleus, the attraction between the electron and its nucleus is likely to be weak; whereas those moving in an orbit closer to the center experience a strong pull. The difference in electronegativity between two atoms can affect the type of bond forming between them.

Ionic bonds are produced between atoms with significantly different electronegativity. One atom attracts the pair of electrons much more strongly than the other one does so that the stronger one has all the electrons and the other one loses its electrons completely. This makes both atoms charged: one positively and one negatively. These two atoms will be held together by electromagnetic attraction as the oppositely charged atoms attract each other.

Chemical bonds formed between atoms with similar electronegativity are likely to be covalent bonds in which atoms share electrons to achieve a more stable electromagnetic configuration. None of the participants will appear to be negatively charged or positively charged as in ionic bonds. The paired electrons are shared between them because they have similar electronegativity so neither can pull the electrons to itself completely. It is like a tug of war between two evenly matched opponents.

A difference between the electronegativity of each of the particles will make a chemical bond polar or nonpolar. In a nonpolar bond, the shared electrons, i.e., the

bond, are located between the two parts, but the one with higher electronegativity exerts stronger attraction on the paired electrons than the atom with lower electronegativity.

When two electrons are shared between two atoms, the atom with higher electronegativity holds the shared electrons closer to itself. Because electrons are negatively charged, this skewing marks the side closer to the electrons appear to be negative, and the end further away from it appears to be positive.

Another type of chemical bond is the metallic bond. This bond occurs in metals where a lattice of positively charged metal ions is held together by a delocalized “sea” of electrons. There are delocalized electrons in solid metal because these elements all have a very loose hold on their outermost electrons. So when two metal atoms are close enough to be affected by each other’s electromagnetic force, these outermost electrons can move freely in this area – they are delocalized. This happens between all neighboring atoms. Passing from one atom to another in a lump of metal, the delocalized electrons move freely as a sea of electrons. Losing a firm hold of the outermost electrons, the metal ion becomes positively charged, i.e., metal cations. They are all held together by the electrostatic attraction between the delocalized electrons as a whole and the cations. Because all the cations are positively charged, they repel each other. As a result, each of them keeps an equal distance from its neighbors and does not move away from there. Moving away from the particular spot would mean moving closer to another atom, which is repelling it because they are both positively charged. As a result, cations in the sea of delocalized electrons form a lattice. Metals have this particular structure because their electromagnetic force configuration allows their electrons to move freely through all neighboring atoms. Electrons in metals are not

associated with any particular nucleus as are the electrons of non-metallic substances. Since electrons can move freely throughout their whole structure, in comparison with non-metallic materials, they are chemically inactive but highly conductive of electricity. Electrons are held firmly by all nuclei in the structure, so it is hard to lose or gain electrons and participate in any kind of chemical reactions. Electrical processes are facilitated, for current can pass through the sea of free electrons without giving or “grabbing” electrons from any particular nucleus as the current passes through.<sup>88</sup>

In sum, chemical reactions, which consist in the formation and breaking of chemical bonds, are made possible by electromagnetic phenomena. The electromagnetic attraction of the positively charged nucleus holds the negatively charged electrons in orbit around it in “electron shells”. An atom can gain or lose electrons when it is affected by the electromagnetic force. This force is so weak that it is only effective when two atoms are in very close contact. Hegel was not aware of the mechanism, but he did note the importance of close proximity. The electrical attraction between nucleus and electrons holds the electrons in their orbits. It is also the very force that holds atoms together to form particular molecules. The structures of electron shells determine how atoms will interact with each other when in close contact, because different configurations will wield different electromagnetic forces upon their outermost electrons. The behavior of these electrons when disturbed by the electromagnetic field of other atoms constitutes the chemical reactions that happen in chemical processes. In

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<sup>88</sup> This contrast in activeness is also a sign that chemical reactions are different from electrical reactions, although their essences are the same.

Hegel's discussion, this electromagnetic structural disposition is the chemical affinity. Modern chemical theory adds a detailed explanation of such affinity.

Today, it is clear that the difference between electrical processes and chemical processes is that the former do not alter the molecular structure of the participants. Although Hegel does not have that knowledge of atomic theory, the concept he was using, shape, still denotes an unchanged structure which is responsible for the chemical identity of different factors. Materials that undergo electrical alterations only lose or receive free electrons during the process. Their atomic and molecular structures are unaffected. Neither charging nor discharging electrical energy produces anything with new properties: the processes merely redistribute electrons. In this sense, these atoms and molecules are merely bearers of the transmission of electrical charges, but their qualitative structure stays untouched. Electrical processes only act upon them superficially.

Electrical processes can, nonetheless, change chemical reactivities in some cases. These kinds of influence are classified as electrochemical effects because they involve the chemical impact of electrical phenomena such as current, voltage and electrolysis on chemical reactions, and vice versa. Transfers of charge, migration of ions, and electrolysis can affect the progress and reactivity of chemical reactions. The core of chemical reactions is the changing of the qualitative structure of atoms by rearranging electrons to form or break chemical bonds. Therefore, the behavior of electrons can affect, and be affected by, chemical properties. Electrolytic reactions only occur during electrolysis: this requires the use of external power sources to drive

electric current through an electrolyte solution or molten salt. This external power is required to initiate and sustain the processes.

One example of electrolytic reaction is the electrolysis of water. When a current passes through water, hydrogen and oxygen are produced at the negative electrode and the positive electrode respectively. The overall reaction is a chemical process as water molecules are broken into their constituent elements. However, part of the reaction is electrical in nature. Water molecules are polarized because of the uneven distribution of electrons in them. Oxygen is more electronegative than hydrogen, so oxygen pulls the shared electrons in the covalent bonds closer to itself. Leaning towards the oxygen atom in water molecules, electrons make this end appear to be negatively charged, and the other end appears to be positively charged. Yet they are considered only partially charged as there is no genuine transfer of electrons – the electrons are only leaning toward one end. The production of hydrogen starts, using the positively polarized end of the water molecule, by attracting two free electrons at the negative electrode. This is an electrical phenomenon, not yet a chemical process.

Electromagnetic processes can change chemical properties of substances by affecting, but not changing, their molecular structure.

In several of the examples mentioned above, we see that some chemical reactions start by breaking down substances into ions. This can only happen with external help – for example, by dissolving in a solvent, by heating up the material, or with a catalyst. Hegel is aware that chemical reactions are finite in that they need to be mediated by water, air, or some other materials. He cannot explain the mechanism behind that. The atomic theories make it clear that some molecules need external help

to break some chemical bonds within them before they are reactive enough to go through chemical changes.

### 3.3.2 Further Modern Classifications of Reactions

Contemporary knowledge of chemistry provides several further ways to classify reactions. For example, chemical reactions can be classified according to the direction of energy flow during the reaction. There are exothermic reactions, where the reactions release energy, and endothermic reactions, in which the reactions absorb energy from the surroundings.<sup>89</sup> Another contemporary classification divides chemical reactions into five basic types: combination, decomposition, single replacement, double replacement, and combustion.<sup>90</sup> Combination is where two or more reactants combine to form a single product. Decomposition breaks down a single compound into two or more products. Displacement is the process in which an element in a compound is substituted by another element. In double replacement, two compounded reactants exchange one of their constituent compounds to form two new molecules. Combustion involves changing the oxidation state of the reactants, forming and breaking bonds between elements and oxygen. These divisions are determined through molecular relations of which Hegel was ignorant, but they do not compromise Hegel's classification of the chemical reactions. These contemporary classifications merely subdivide Hegel's classification with further details. Combination and decomposition clearly match Hegel's

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<sup>89</sup> Atkins and De Paula 2014

<sup>90</sup> Most of the classification systems agree with each other on the first four types, but not on the last one. Some will name the last category as "oxidation-reduction reactions"; the essence of this type is that the oxidation state of the reactant (s) changes during the process. There are practical reasons to give it an individual category, but for the purpose of this discussion, we should be aware that oxidation, for Hegel, is a combination of an element and oxygen, whereas reduction is the dissociation of an oxide taking oxygen away from it.

combination and dissociation by consisting in building and breaking chemical bonds between atoms respectively. Displacements, single and double, involve breaking chemical bond (s) in the reactants and forming new bond (s) in the products. They can be considered as compounds of combinations and dissociations in Hegel's sense. For example, a single displacement has the form:  $AB+C \rightarrow B+AC$ . The reactant C replaces the B in the compound reactant AB. There are two things that happen in this reaction: the bond between AB breaks, and the chemical bond between AC forms. It is a dissociation and a combination. Contemporary study of molecules informs us that the form of this displacement can be more complicated. The key is that the breaking of the old bond and the formation of the new one do not necessarily happen in a sequential order. In some cases, these two happen at the same time. This is called a "concerted" process.<sup>91</sup> In such cases, it is chemical C's approach that weakens the bond between chemicals A and B. There is a transitional state in the reaction where the new bond is partially formed, and the old bond is partially broken.<sup>92</sup> This is the reason why contemporary scientists think a single replacement should not be considered as a dissociation followed by a combination: these two rather merge together. The situation is similar in double replacement and oxidation-reduction reactions: they consist in dissociations and combinations.

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<sup>91</sup> Atkins and De Paula 2014

<sup>92</sup> There are more possibilities in double replacements, I will not go through the details here since the example of single replacement is sufficient to demonstrate my point in this discussion. Details of the mechanism of double replacement can be found in the book mentioned in the previous footnote.

### 3.4 Conclusion

Our current knowledge provides us with significant details of chemical reactions that Hegel's classification does not address. Nonetheless, there are still only two things that can happen between factors in a chemical reaction: bond formation and bond breaking. Whatever the reason behind these changes and the sequential order in which they happen, these are the only two authentic chemical interactions that can occur between materials. At least one of them must take place in every chemical reaction. When we look at chemical reactions between complex chemicals as a whole, the contemporary classification reveals different mechanisms on a molecular/atomic level. There is no contradiction between these two types of classifications; they merely focus on different levels. The two-division classification is more fundamental, while the five-division-classification is more practical in our contemporary study of chemistry.

Hegel has successfully established an objective determination of chemical processes extending the conception of nature beyond the Kantian mechanistic frame. With this determination, transformations between chemically differentiated materials are objectively knowable. Hegel's framework for understanding chemistry is influential for the development of chemistry today, even though his specific ideas about the nature of matter and chemical processes have been supplemented by modern science. Contemporary theories of atomic/molecular structure and chemical bonds provide us with more concrete and detailed research through which to extend Hegel's achievements.

Having objective understanding of the chemical transformations between materials, the next step in the inquiry into life is to provide an objective understanding of the purposiveness to which Kant alluded, without providing knowledge. In the following chapter, we will examine Hegel's insight into how chemical reactions can be integrated into a biological system that can exhibit a self-sustaining character under certain conditions. Hegel suggests that the purposiveness, which so perplexes Kant, can emerge through self-sustainable complexes of chemical processes.

## CHAPTER FOUR

### UNDERSTANDING THE JUMP TO BIOLOGY

In Hegel's study of nature, what he calls "chemism" exhausts all the possibilities in inorganic nature. Chemical processes form the phenomenon which has all inorganic physical phenomena integrated into it. A chemical process is finite in two senses: first, it always depends on external conditions; second, the results and the starting point are always different. Once chemical processes overcome these two limitations, we are outside the perimeter of inorganic nature – we are in a world populated by organic beings. Hegel does not pursue a general and universal concept of life, or a minimal form of being alive after closing his discussions on inorganic nature. He aims to show that, following the path he has established, we can have objective knowledge of biological processes.

#### 4.1 Hegel's View

Hegel suggests that if the products of chemical reactions spontaneously renew those reactions, that process would exhibit life. First, we will try to obtain objective knowledge about how chemical reactions can be integrated into complex systems with self-renewing characteristics, and whether or not such systems are sufficient to account for the distinct features of life. Developments in biochemistry have provided us with many advanced details about the mechanics of the phenomenon of life. Although there

are many different modern approaches to understanding the essence of life, many scientists base their work on the same fundamental belief Hegel proposed – that life can be understood through its constituent chemical reactions.

#### 4.1.1 Forming an Organic Unity

Hegel emphasizes the fact that the beginning and the end of chemical processes are separate and distinct. He makes it clear that this fact about chemical process also “constitutes its finitude which keeps it far from Life and distinguishes it therefrom” (Hegel and Miller 2004, page 269). This gives us a hint about the essence of biology. It is clear that each distinct biological process, i.e., metabolism, growth, reproduction, all involve qualitative transformations of materials – only chemical reactions can make these transformations possible. Chemical properties only express themselves through chemical processes. Chemicals interact in terms of their distinct chemical natures. We can only know the flammability of phosphorus when it is in combustion. Before the combustion, phosphorus only shows its weight, hardness and other physical properties. However, its flammability is also destroyed in the chemical processes. After burning, phosphorus transforms into phosphorus pentoxide ( $P_2O_5$ ) which is itself no longer combustible – the chemical process destroys the combustibility while revealing it.

Chemicals are predisposed to enter certain kinds of combinations and decompositions due to their atomic and molecular structure – chemical reactions can provide some kind of continuous activity. Following this thought, when one chemical reaction comes to an end, there are two ways that chemical reactions can continue . One is to have many chemical reactions to form a long chain of reactions – just like a row of dominoes. In this situation, the products of each reaction can automatically join

another reaction. The desired material and environmental conditions must be available. Such conditions include the appropriate pressure, temperature, the other reagents of the proper affinities are in proximity and so on. In this way, the chemical activity can be extended beyond one single reaction. The other one is to form a circle instead of a chain. Hegel must have this model in mind because he suggests that chemical processes are distinguished from biological processes by the distinction between the materials at the beginning and at the end of the processes. This suggests that a biological process needs to end in the same situation as the one it started with. Hegel claims that “if the products of the chemical process spontaneously renewed their activity, they would be Life” (Hegel and Miller 2004, page 269). The emphasis on *renewal* can help us understand what life is in Hegel’s mind. *Renewal* suggests that it is the very same reactivity that works again. In the model of a chain reaction, nothing is renewed. In a chain reaction a becomes b, then b becomes c, and so on. The first reaction is not renewed – only a second reaction happens immediately after it. The two reactions don’t even occur at the same time – before the first one comes to an end, the second does not have the desired reactants it needs to start with. In this sense, a chain reaction is not self-renewing; It is a group of separate chemical reactions linked together due to the fact that each of the reactions, except for the first one, can only be triggered by the products of another reaction in the series. Each reaction is related to the reactions before and after it, but is not really related to other reactions in the group.

In Hegel’s system, the second process, where the same group of reactions gets constantly renewed, is finite in the same way as chemical processes, but it is also

infinite as much as it is finite.<sup>93</sup> It is finite in the sense that its continuity is subject to external conditions. In the previous section we saw how chemical reactions are conditioned by external conditions. Life, as an integrated system of chemical reactions, is not only subject to those conditions that matter for chemical reactions; it is likely to have more external conditions for its maintenance.<sup>94</sup>

Aside from self-renewal, forming an organic unity, which consists of organs that engage in complementary functions to sustain one another in a whole to which they belong, there is another important feature that distinguishes life from chemical processes. Hegel claims that “Life is present in principle in the chemical process; but inner necessity is not yet existent unity” (Hegel and Miller 2004, page 270). Although the existence of chemical processes already has everything required for biology to emerge, life only arises when some chemical processes constitute an organic unity by their combination. In a chain reaction, there is no defined unity for the reaction. The chain is always reaching out for something that it does not already have. Each reaction is only related to those before and after it. There is no necessary connection between reactions further apart in the chain. It may be tempting to consider the whole chain, from the beginning to the end, as a unity. Each of these reactions, or any section of reactions of the chain, can exist apart from the chain. This unity, therefore, has no inherent necessity: if a chain, say with ten reactions, is interrupted in the middle, each section of the chain has the same unity as the whole chain has. In contrast, each reaction in the circular model only exists by being a part of the unity – if any one of them is removed,

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<sup>93</sup> Hegel and Miller 2004, page 269

<sup>94</sup> This will be discussed in detail in the next Chapter on Geological organisms.

the system will lose its defined unity. The existence of each part depends on the continuous existence of the unity. So it is clear that a living being, in Hegel's understanding, must be a system of interrelated chemical reactions that can always go back to the situation it begins with and continues with the reactions spontaneously. The system of chemical reactions achieves continuity with this self-renewing function.

It is important to be aware that biological processes do not start and end in the same sense as physical or chemical processes. In the discussions above, we talked about biology as a system of chemical reactions which can always come back to the place it began. The "beginning" and "end" are used only to describe the continuity of the system which emerges from the chain of chemical processes. As soon as the beginning and the end coincide, the group of reactions can kindle itself again – the biological process begins; that is to say, the biological process does not start with the static proximity of chemicals, but starts with the formation of the dynamic system.

There are certain chemical reactions that are not organic in nature that appear to be self-renewing because they occur in an oscillatory manner. They are still inorganic because they do not renew themselves in the circular manner that we always find in organic beings. These kinds of reactions, although appearing to be self-renewing, are not self-renewing in nature – they only have a particular pathway to finish the reaction. It is important to distinguish life from these chemical reactions that persist in their continuity by an oscillatory matter. The essential difference between a self-renewing process and this kind of *pseudo* self-renewing process is clear when we consider the Belousov-Zhabotinsky (Belousov-Zhabotinsky) reaction, which is a good example of an

inorganic reaction which is often mistakenly considered a self-renewing or self-sustaining chemical reaction.

Belousov-Zhabotinsky reactions are a class of reactions that serve as a classical example of a nonlinear chemical oscillator.<sup>95</sup> The Belousov-Zhabotinsky reaction is far from equilibrium and remains so for a significant span of time, leading to an apparent self-renewing, oscillatory behavior. The typical Belousov-Zhabotinsky reaction involves a mixture of bromate ions, cerium ions, and an organic substrate such as malonic acid.<sup>96</sup> The exact set of reactions can vary depending on the specific reactants and the conditions. In some cases, the reactions can be much more complicated. Cerium in this example is merely a catalyst that oscillates between a +3 and +4 oxidation state. Oscillation between these two states makes the color of the solution indigo and yellow respectively.

Belousov-Zhabotinsky reactions are a kind of self-renewing reaction as they have the ability to sustain an oscillatory behavior over a certain period of time. The reaction will stop when one of the reactants is used up.<sup>97</sup> In two aspects, these reactions are different from the self-renewing reactions which we discussed earlier as the essence of life. On the one hand, these reactions are not self-renewing in the sense of being able

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<sup>95</sup> A chemical oscillator is a complex mixture of reacting chemical compounds in which the concentration of one or more components exhibits periodic changes.

<sup>96</sup> The essence of the Belousov-Zhabotinsky reaction is a cycle that repeats itself. The following is a simplified version: 1) The bromate reacts with the organic substrate (often malonic acid) in the presence of acid, producing bromide ions. 2) The bromide ions react with more bromate, producing bromine. 3) The bromine reacts with the cerium (IV) ions, reducing them to cerium (III) ions and being consumed in the process. 4) The cerium (III) ions react with more bromate, being oxidized back to cerium (IV) and producing bromide ions. 5) The bromide ions can then react with more bromate, starting the cycle again.

<sup>97</sup> This is also an autocatalytic reaction in the sense that some of the products of the reaction feed back into the reaction process to continue the reaction. Autocatalytic reactions are also considered a possible stereotype of life. This will be discussed more in the following chapter.

to replace their reactants. Once the initial reactants are exhausted, the reaction will stop whereas in the self-renewing process in organic beings, the reactants are only of the same kind, but not exactly the same as before.<sup>98</sup> To a certain extent it is better to consider the apparent self-renewing character as a particular way the reaction proceeds. Most chemical reactions happen in a linear way. For example, in the reaction between soda and acid, when mixing the reactants together, bubbles appear. This reaction goes in one straight direction – it cannot reverse to the original composition of reactants – soda and acid.<sup>99</sup> In comparison, the Belousov-Zhabotinsky reaction takes a particular path, a back-and-forth one, to eventually finish completely. The oscillation is different from a genuinely self-renewing mechanism in the sense that the materials, the very same molecules in the reactions, are recycled again and again before the reaction is completely finished – what is maintained in the reaction is not only the mechanism of reaction, but also the same molecules. With the same materials in the reaction, the same reaction is only unsettled rather than being renewed. However, one important aspect of the living system is the ability to initiate interactions with its environment – metabolism. This interaction is about assimilating materials from the environment, and discharging materials back to the environment. As Hans Jonas suggests, in the life process, what is renewed is the process itself, but not the materials.<sup>100</sup>

The apparent self-renewing behavior of the Belousov-Zhabotinsky is analogous to a pendulum. In an ideal situation where there is no energy loss of any kind, the

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<sup>98</sup> For example, a plant always needs nitrogen to sustain its living function, but the nitrogen in the reactions is always new nitrogen freshly absorbed in its environment, not the same nitrogen as used before.

<sup>99</sup>  $\text{Na}_2\text{CO}_3 + 2\text{HCl} \rightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2 \uparrow$

<sup>100</sup> Jonas 2001, page 75

pendulum can go back to its original position making the motion perpetual. However, the motion of a pendulum is in no way the same as the motion of an animal because the motion of the pendulum is not initiated by the object itself – it is started by an external force, say a push, and maintain by the gravitational force<sup>101</sup>. In this sense, Belousov-Zhabotinsky reactions have the ability to repeat the exact same reaction with the very same materials, yet they are different from the self-renewing reactions we discussed above where different molecules of the same type flux through the same kind of reaction to prolong the reaction – organic processes do not recycle their own materials to renew the processes.

The concept of organic chemicals is not discussed by Hegel. It is a contemporary “artificial concept”. Organic and inorganic materials differ from each other only in whether they are integrated into organic beings – the distinction is subject to their integration into a unity. Examining the material itself, say carbon molecules, cannot genuinely reveal whether it is organic or not. It is a functional distinction. Any chemicals can play an organic role – we only have vague concepts of organic materials based on the situation on Earth – things could be very different on a different planet where life might not be carbon based. Containing carbon hydrogen (C–H) bonds is the most common identifying feature of organic materials in today’s terrestrial chemistry. However, there are inorganic compounds containing this bond, such as methane (CH<sub>4</sub>). The clearest distinction between organic and inorganic materials resides in where they originated: the concept of organic materials is identified by their ability to interagency into organic unity. This distinction is based on the assumption that living beings and

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<sup>101</sup> The difference between these two kinds of motion was discussed in the critique of Aristotle’s theory of life earlier.

nonliving beings are based on two objectively different kinds of material, namely, organic materials and inorganic materials respectively. So-called organic processes are merely chemical reactions integrated in a particular way to form a unity; he would certainly not agree that they have different material constituents. From Hegel's perspective, this distinction between organic and inorganic materials, i.e., containing carbon hydrogen bonds, is simply because some materials are more likely to participate in self-renewing reactions. It is the same as some chemical reactions being less likely to form self-renewing systems, e.g., the rusting of iron. Therefore, it is not necessary to distinguish organic beings from inorganic ones based on the nature of their materials.

To support this point, we should notice that organic beings, e.g., flowers, only absorb inorganic materials from the external environments to maintain themselves.<sup>102</sup> Materially, organic beings are constituted by inorganic elements: how they are organized makes them exhibit specific biological properties. Winfield (2017) points out that certain plants can feed on inorganic elements exclusively, for example, *Tillandsia*. Those plants are commonly known as air plants because they do not require soil to grow and can survive in a wide range of environments. *Tillandsia* obtains water and nutrients primarily through specialized structures found on their leaves. Being air plants, they obtain all their needs from the sun and water in the air. With our more advanced knowledge of plants in general, we know that there is a wider range of plants that can

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<sup>102</sup> Organic fertilizers are used in all growing plants. Organic fertilizers are fertilizers that are derived from organic sources such as plant and animal matter. They are only *quasi* differentiated from inorganic fertilizers if it is true that certain materials can only be obtained from living beings. However, as discussed in the previous paragraph, the difference between organic and inorganic materials is not real. In the next section "Two Major Developments in Biology", we will see that from 1827, scientists are able to produce organic materials, in the sense we normally consider them, from inorganic materials in laboratory settings. Therefore, what is called organic fertilizer is only organic for the resources out of which they are easy to produce. With sufficient technology, there should be no difficulties in producing them from inorganic materials.

feed on inorganic nutrients exclusively. The popular hydroponic system gives us a clear idea of what plants need in their growth. A hydroponic system is a method of growing plants using a nutrient-rich water solution to deliver essential nutrients directly to the plants' roots. Many common plants can even grow better in hydroponic systems since the nutrients can be precisely controlled according to the needs of the plants.

Is there any significant deficiency resulting from feeding on inorganic nutrients exclusively? This is a controversial topic that has attracted many studies. However, in our current discussion, we only need to ask if feeding on inorganic food exclusively will make the plant lack any characteristics of being alive, e.g., compromising its fertility, shutting down its metabolism and so on. The answer is no, because on the one hand, there is no strict distinction between organic and inorganic food, and on the other hand, everything animals and plants have been consuming are inorganic in the sense they are not alive – we consider some foods organic because we naturally obtain them from living beings. So there is no doubt that plants can feed exclusively on inorganic nutrients. As a matter of fact, plants living in the soil normally absorb nutrients in their inorganic form. Understanding this fact led us to develop the hydroponic system in the belief that it can provide plants with appropriate nutrients. Does organic fertilizer impact the current discussion? Being organic is being alive – with a self-regenerating ability at least.<sup>103</sup> Living beings do not depend on special material constituents to maintain their identity because they obtain and assimilate inorganic material exclusively: their material constituents are the same as inorganic things. It is their particular organization, i.e., forming an organic unity, which allows them to maintain themselves by assimilating

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<sup>103</sup> Although we are still trying to figure out what it really means to be organic, having a self-regenerating ability can be an acceptable general property that organic beings are likely to have.

materials from their environment and integrating those materials in an organic way, that makes those things organic.

The environment of organisms provides them with the materials and relatively stable enabling conditions for the chemical processes within living beings to renew themselves continuously. This function can only be actualized by chemical processes because they involve transforming what is in the environment into something different – some organic constituents of the living system. Chemical processes are the only processes in the physical world that can transform one material into a different material (s) – mechanical, electrical and magnetic processes cannot.<sup>104</sup> Furthermore, chemical processes can be sufficient for such a self-maintaining system, with appropriate external conditions, because the change is powered by the electromagnetic forces inherent in their structure – the chemical affinity. It is the particular integration of chemical reactions that enables the inorganic materials to acquire biological characteristics.<sup>105</sup> With this understanding of the self-renewing system, we need to examine whether or not it is sufficient to account for the characteristics of life.

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<sup>104</sup> Nuclear transformations can also change one material to another. However, considering the enormous energy required for such transformations, they can only be achieved within stars, nuclear reactors and cyclotrons and so forth – nuclear reactions are incompatible with the condition of living things.

<sup>105</sup> This is still different from organic material nowadays. Having biological characteristics is about being alive, whereas organic materials in our common sense include lifeless materials which were alive, or have certain characteristics which are commonly found in living beings.

## 4.2 The Chemical Processes are Sufficient to Account for the Three Characteristics of Life

The three essential processes of life are: 1) organic unity, 2) metabolism, and 3) reproduction. Hegel's understanding of these three biological processes depend upon self-renewing chemical reactions. Hegel himself does not offer a comprehensive definition of life after finishing his development of Chemistry. His next step is to study three specific stages of life. He aims to show how the fundamental characteristics of life are objectively determined. This aim frees Hegel from showing whether a minimal form of life exhibits all these qualities – if he can prove an advanced life form can be objectively determined, he still achieves his goal. His discussion of life addresses how the integration of chemical reactions acquired into a self-renewing system can objectively account for the three life functions that Kant had correctly outlined without being able to know them objectively.

### 4.2.1 Organic Unity

As discussed in the previous chapter, chemical processes are finite by nature. One reason is that they always depend upon external conditions. These enabling conditions include material conditions such as having the reactants in proximity and environmental conditions such as having appropriate humidity, temperature, and pressure. Biological processes are differentiated from chemical ones by overcoming these external conditions. One of those external conditions which needs to be overcome is having chemicals in proximity. The identifying characteristic of chemical processes is that the products are chemically different from those they start with. Yet to overcome the barrier of the need for proximity, the products must be the same as the chemicals at the

beginning and be kept within the organism.<sup>106</sup> Therefore, a chemical system with self-renewing function must be constituted by more than one chemical reaction. This was discussed in detail in the previous chapter on Hegel's classifications of chemical reactions. To renew themselves, all the chemical reactions in the system must be enabled by each other and enable each other. Only then can the system of chemical reactions overcome external dependence.

With chemical processes being the enabling condition for one another, a new mode of organization irreducible to chemical processes emerges. This is only possible due to the inherent quality of chemical processes – they always depend upon external conditions. Each chemical process is a part of this organic whole by contributing to the self-renewing process. Organic beings do not retain the same individual materials, but do retain the same chemical processes, which go on through an exchange of materials with the environment. Hegel noted that chemical processes in organic beings are constantly destroying their material constituents while creating them. This suggests that organic beings sustain themselves by constantly transforming themselves materially, assimilating new material from the environment and creating waste. This process of material exchange is distinctly biological in several senses.

First, the material of each part of the whole does not have organic activity before performing its function in the organism. Functionally, an organ, say a heart, can only function in the way it is supposed to when it is working with other organs as an organic unity, and materially, each organ is constantly generated by the system. A system of

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<sup>106</sup> They have to be physically contained in the organism so they remain in proximity. That is why the cell has to have a membrane.

chemical processes with self-renewing function can account for the way in which components of living things can interact to form an organic unity.

A chemical process can occur without being in an organic system; however, it does not perform any biological function as it does in an organic system. In this sense, components of an organic system cannot exist as such independently from the system because their organic identity depends on their function, not their material existence.

To form an organic being, all chemical reactions in the system must form an organic unity by being at once the cause and effect of each other. The way different organs of plants, for example, work together demonstrates how organs can form an organic unity. Different organs perform different functions to sustain one another. Reactions happen in different organs of a plant. For example, roots absorb water and minerals from the soil. The leaves need the water and nutrients to be able to grow, breathe and perform photosynthesis. In this sense, the roots are the cause, and leaves are the effects. Meanwhile, without the respirations and photosynthesis in the leaves, roots cannot grow. That is to say, the leaves cause the roots. Therefore, leaves and roots are causes and effects of each other at once. There are cases where plants can grow back after they were cut down to their roots without any leaves. In this process, it seems that the roots cause the leaves without being caused by the leaves. However, the growth of these roots is caused by the nutrients the old leaves made. Those nutrients are stored in the stems and roots of the plant. The roots would not continue to work if they were not driven by the growth of the new leaves. The bare pruned plants cannot survive if they do not grow new leaves after a period of time when the stored energy is used up. This suggests that the normal and stable status of a plant requires

the roots and leaves to function in a complementary manner: they are causing each other at the same time.

To be an organic component of the system, one of the requirements is that the process must be caused (be activated) by another component(s) in the system. In the case of plants, a leaf must receive its nutrition from the plant itself, i.e., its function is caused by this very plant, to be considered as part of this organic unity. A chemical process which contributes to the maintenance of the system without being caused by the other processes is not a component of an organic unity. Plants need to absorb nitrogen from the soil - the reaction which produces the nitrogen is not a part of the self-renewing system because it only causes the function of other processes in the system, but is not caused by the other processes in the system. So, all the reactions in the organic unity must be caused by other reactions in the system. In a similar sense, to be a component of the organic unity, each reaction in the system must cause other reactions. If one reaction does not cause another reaction(s) in an organic unity, then either this reaction is irrelevant to this system, or it is only a product of the organic unity on the environment, for example, sweat. For example, the oxygen produced by the organic function will react with other chemical processes in nature, say the oxidation of iron. Because this chemical process does not cause any other process which sustains the plant, the oxidation of iron is not part of the organic unity. Therefore, to constitute an organic unity, each and every component must be caused by the others, *and* cause others. The self-renewing system of chemical processes makes this feature of organic beings possible. Inorganic processes before chemical ones cannot constitute organic

beings. Although they are also finite by being conditioned by external factors, they do not have the vitality,<sup>107</sup> as Hegel names it, to overcome their limitations.

Our understanding of organic unity gives us a further insight into why the Belousov-Zhabotinsky reaction, mentioned earlier, is not a valid model for organic unities. Each of the reactions in the system comes one after another instead of functioning simultaneously as an organic part of the reaction. In an organic unity, it is important that each and every reaction is constantly working. Once it stops, the life process is disrupted. It cannot naturally resume the same organic organization. The organic unity is actualized by the interdependent relation of the chemical reactions in the group.

#### 4.2.2 Metabolism

A mechanical understanding of the world cannot account for the qualitative differences between materials as it only differentiates them by quantitative mechanical properties such as mass and shape. Hegel has little knowledge of the empirical details of metabolism, but scientists in his time started to explore how an organism's chemical reactions process substances from its surroundings to maintain itself. Such metabolism is only possible with combinations of a variety of chemical processes, because it involves profound transformation of materials. Living beings maintain themselves through transforming what is outside into a part of themselves.

One of the characteristics of life is that an organism sustains itself by transforming what is in its surroundings into a part of itself, e.g., plants assimilate nitrogen, which is absorbed from the soil, into its own living material. How does the fact

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<sup>107</sup> Hegel and Miller 2004, page 269

that materials are chemically differentiated make such transformations possible?

Nitrogen in the soil cannot become a part of the plant and stay unchanged. Because Kant limits his concept of nature to a mechanical understanding of the world, he cannot comprehend the process of assimilation in life. On the one hand, mechanical processes do not qualitatively differentiate materials. On the other hand, mechanical changes do not transform materials. Chemical processes do make possible the essential life processes that Kant observes. Kant cannot explain how a seed turns into a leaf, nor how a tree can grow bigger by exchanging material with the environment. A seed, in an appropriate environment, can turn into something much bigger than its original size, with very different qualitative properties. In Kantian mechanistic nature, materials cannot grow in the way that organic beings grow. Growth involves the increase in size of this organic unity as well as the maturities of their functions, and aging, i.e., losing their functions. All these processes always come in a certain order, and are dictated by the organic being itself. The increase in size is normally associated with the maturing of functions and the aging processes always come after maturity, accompanied by, in many cases, a decrease in size.

The physical increase in size that occurs in crystals is often mistaken for biological growth. From a physical perspective, the growth of crystals seems to be spontaneous: the new material becomes a part of the original crystal by losing its own form and taking on the structure of the crystal. However, there are two essential differences between crystal formation and original growth. First, in the growth of an organism, the new materials added not only lose their original structure, but also their identities: their qualitative character becomes very different as they become assimilated

into the organic being. This is a chemical change as it involves transforming one material into another: a plant does not incorporate leaves from its environment, but uses external materials to grow them. In crystals, the materials used for the growth stay chemically unchanged throughout the whole process; they are only deposited from the solution. What changes is how their molecules are geometrically organized. During this process, certain physical properties may be changed: the level of opacity, the color, the odor, the conductivity, and, very often, the state of matter. These changes can be observed in some chemical processes, yet, in the case of the crystals, these changes are caused solely by the arrangement of the new added molecules that the crystal absorbs from the environment. Those components will stay unchanged in the crystal structure. They do not form new chemical bonds with other materials, and they do not break chemical bonds in other materials.

Another essential difference between the formation of crystals is a process that is generally reversible, yet biological growth is a chemical process which is almost never reversible. For example, when we evaporate water from saturated salt solution, salt crystals deposit at the bottom. As the process continues, the size of the salt crystals increases. This process can be reversed by adding more solvent or increasing the temperature.<sup>108</sup> In comparison, biological growth, which equates to chemical processes, is never reversible. Losing weight is a decrease in size, yet it does not reverse the original growing process — reversing that process means the fat on one's body reverses to the original food one took. This difference once again clarifies that growth is a deeper change than the formation of crystals.

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<sup>108</sup> Increasing temperature does not always increase the solubility of the solvent, yet it is the case for most of the solid solutes.

### 4.2.3 Reproduction

The third characteristic for a living being is reproduction: how individual plants are the cause and effect of the species they belong to. Self-renewing chemical systems do not necessarily reproduce. The essence of reproduction is to multiply individuals' organisms with possible modification to increase their adaptation to the environment. The first difficulty concerns how a unified group of chemical reactions can be individualized as the group does not necessarily produce its own boundary. Then, when chemical reactions increase in quantity, they still carry the same reaction, only with more materials involved: this is different from starting another individual group of reactions. Another difficulty is that reproduction is not only the multiplication of the number of individuals, but also the preservation of a shared identity making them members of the same species. This requires a method of preserving and copying information from one generation to another.

Contemporary studies in science seem to show, however, certain pure chemical systems can easily provide “asexual” reproduction to meet the requirement of multiplication in number. The system is individualized when it reaches a certain number. It is easy with primary self-renewing systems as there are not many functions involved. In recent years, the study of lipid vesicles as models for early life forms offers insights into how simple life forms may have originated from simple chemical systems.<sup>109</sup> Lipid vesicles are formed spontaneously as a response to an aqueous environment. A lipid

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<sup>109</sup> Lipid vesicles are spherical structures formed by a bilayer of lipids (fatty acid molecules), and they can encapsulate water and other molecules.

has a hydrophilic (water-loving) head and a hydrophobic (water-repulsing) tail.<sup>110</sup> In an aqueous environment, they arrange themselves to face their heads towards the water, and orient their tails away from the water. The collective result of these individual actions is creating a lipid bilayer that can close to form a lipid vesicle. This vesicle compartment creates an inside environment distinguished from the external environment. This boundary can form spontaneously under the right conditions as it is the result of electromagnetic forces between polarized molecules.

Another important characteristic of the lipid vesicles is that with more lipids in the environment, the vesicle can increase its own size by incorporating them into its bilayer. Furthermore, when a vesicle reaches a certain size, it can also be divided into smaller vesicles. Incorporating new lipids is not the same as growth for the same reason that the growth of crystals is different from the growth of living beings: it is merely a rearrangement of new materials without transforming the new materials into constituents of the organism. However, this spontaneous formation of vesicles makes it possible for chemical systems to multiply because the vesicle can enclose a chemical system in a closed space, then divide the system into two by dividing itself into two vesicles. Reproduction can then be objectively accounted for by combinations of chemical processes.

Although self-renewing systems exhibit the defining characteristics of life, some object that those systems are still much simpler than the common life forms (i.e., plants,

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<sup>110</sup> Hydrophilic and hydrophobic are merely electronic magnetic forces between polarized water molecules and lipid molecules.

humans) we encounter in the world.<sup>111</sup> Although self-renewing chemical systems can be classified as a simple life form, there is debate over whether those complex life forms exhibit the same basic autopoiesis. Even with all the enabling conditions at hand, it seems almost impossible for a rational being to emerge spontaneously in the same way as the lipid vesicles emerge. For Hegel, the provision of requisite developmental paths for rudimentary self-renewing systems to attain a heightened state is not deemed necessary. When Hegel discusses the development in the natural world, say from electricity to magnetism then chemistry, he always focuses on how the previous stage provides necessary conditions for the following stage without looking for factors that could necessitate the existence of the next stage. For example, when electromagnetism is in place, the stage is ready for chemistry to emerge. Yet nothing can predict if, or when, chemistry will emerge, nor when chemistry will be actualized. It is the same case for the self-renewing system of chemical reactions: it is possible to have self-renewing systems in the realm of chemistry, yet nothing can predict nor necessitate its realization. In a similar sense, it is sufficient, for Hegel's methodology, to show that chemical self-renewing systems have the possibility to evolve to a more complex form. That we investigate these questions, however, presupposes that intelligent life has arisen.

#### 4.2.4 Biological Teleology

Living beings always exhibit a kind of teleology – i.e., they take themselves as their purpose by functioning to maintain the existence of themselves, and advanced life

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<sup>111</sup> There are many ongoing studies about whether or not prokaryotic life originated from inorganic reactions. Abiogenesis, that life arises naturally from non-living matter, cannot fully account for how the first prokaryotic cells were formed from inorganic matter, yet there are theories and experimental results that provide us with plausible scenarios. However, not only are these steps subject to ongoing research, the "cells" produced are much more primitive than the modern prokaryotic cells, which are highly evolved and sophisticated. To confirm this developmental pathway, there are at least numerous intermediate stages awaiting to be understood.

forms can intentionally reach for materials which can be used to maintain themselves. Teleology is first manifested in the emergence of life in the self-organizing and self-developing character of the living organism.

Biological purposiveness emerges spontaneously when a complex of chemical reactions starts to maintain itself, i.e., taking itself as an end. This purposiveness is caused, and can be fully understood by material interactions between chemicals. A detailed understanding of life is denied to Hegel by the limited scientific knowledge of his time. Dahlstrom<sup>112</sup> suggests that our contemporary understanding of life is shaped by evolutionary and molecular research. He points out that several important developments in biology are unavailable to Hegel, for example Darwin's publication of *The Origin of Species* in 1859, almost thirty years after Hegel's death; the rediscovery of Mendel and Weismann's account of germ plasma at the turn of the century, population genetics; and the discovery of the structure of deoxyribonucleic acid in 1953. These scientific developments can support Hegel's theory in the sense that they advance our understanding of the objective, material aspects of living beings. Just as chemistry allows us to know more details about life processes than physics<sup>113</sup> does, our knowledge of molecular chemistry enables us to know more about the system of living beings. Our advanced knowledge in biology offers us an objective and material explanation of reproduction and phylogenetic development. Although these developments add many new aspects to biology, they inherited the methodology and structure of Hegel's investigation.

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<sup>112</sup> Dahlstrom 1998, page 177

<sup>113</sup> Physics and chemistry are two separated fields of study in contemporary science. This is different from the way Hegel presents them where chemism is a part of physics.

### 4.3 Two Major Developments in Biology

During Hegel's time, vitalism was still a dominant theory of life. The belief at the time was that organic compounds, what is normally found in living organisms, can only be produced by living organisms. According to vitalism, being constructed of organic material is what distinguishes living beings from inanimate beings, which are constituted by inorganic beings. In a famous textbook, published in 1827, Berzelius, the most influential chemist of that time, claims that there is a vital force in organic materials, which is situated entirely outside inorganic elements.<sup>114</sup> This belief had dominated most of Hegel's time. In 1828, Friedrich Wöhler, a German chemist, successfully synthesized urea, an organic compound in urine, from inorganic materials. This was a significant breakthrough in chemistry as it demonstrated that organic materials can be created from purely inorganic materials without adding any vital force or other things suggested by the vitalists. Following these experiments, many organic compounds were synthesized in laboratory settings in the 1800s.<sup>115</sup> Wöhler's work marks the downfall of vitalism and shapes the study of organic chemicals in the way it is today – a study focusing on their inorganic constituents and their structure instead of searching for the “vital force” which had been supposed to make them transcend the inorganic world.

Another major development is the Miller-Urey experiment conducted in 1953. Chemists Stanley Miller and Harold Urey designed an experiment to simulate the conditions on early Earth to examine the possibility of forming organic molecules from

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<sup>114</sup> Leicester 2013 page 153

<sup>115</sup> Spangenburg and Moser 2009

inorganic materials in a “natural environment”. In this experiment, they use a closed glass apparatus containing water, a heating element and a mixture of gasses which was believed to have existed in the Earth’s early atmosphere. They provided the system with energy, such as electrical sparks, to mimic lightning and UV radiation. Overall, they simulated the environment of the early Earth to the best of their knowledge. After several days, organic molecules, including amino acids — the building blocks of proteins, were formed in this closed environment.

The Miller-Urey Experiment was designed to investigate the possibility of the spontaneous formation of organic molecules from inorganic materials. As Wöhler’s almost work eradicated vitalism in the study of life,<sup>116</sup> this experiment repudiates the necessary existence of an intellectual designer at the origin of life – merely following physical and chemical laws, inorganic materials can spontaneously appear under certain conditions. It is still debatable to what extent the Miller-Urey simulation is true to the conditions on early Earth. The emergence of life happened at a time which is too far away for us to have any concrete knowledge of it; some of the causal factors may never occur again in our geological history. However, demonstrating the plausibility of the spontaneous formation of organic molecules under conditions which may resemble the early Earth has had a long-lasting impact on the study of the essence of life. Instead of digging into what actually happened at the origin of life, many researchers have focused on how to understand the phenomenon of life through physical and chemical

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<sup>116</sup> The possibility of this spontaneous emergence does not assure its necessity. It is still possible that the origin of life in the way we know it originated with a “vital” power.

processes.<sup>117</sup> In other words, these two experiments established the methodology current used in the study of life in mainstream science.

#### 4.3.1 Contemporary Theory of Life

Today there are new approaches to how we should answer the question “What is life?” Unlike in the days of Aristotle or Kant, current scholars do not just want to use a conceptual framework to catch some common characteristics of the entire collection of living organisms that exist. In *The Principle of Life*, Tibor Gánti addresses the two most common strategies that are used to catch the essence of life – they are known as the bottom-up method and the top-down method.<sup>118</sup> The top-down approach tries to abstract certain characteristics which are shared by all living creatures – it starts with complex life forms and tries to find common characteristics that are shared by all of them by eliminating any particular properties that some of them do not possess, for example having wings; whereas the bottom-up approach takes the opposite direction – it works on creating the simplest life from inorganic chemical reactions trying to determine from which point the group reactions can be qualified as alive. The change of strategy is grounded in scientific developments. In the times of Aristotle and Kant, there was little knowledge of biological chemistry or cellular theory. The most practical route available was to define life: either given by, or as determined by Divine power.

Hegel takes advantage of the scientific development of his time to use a bottom-up approach in his study of the phenomenon of life: studying the developmental path from very basic beings to the most complex beings in the natural world – life emerges

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<sup>117</sup> Physics and chemistry in the modern sense, not the Hegelian sense in which chemistry is a part of physics.

<sup>118</sup> Gánti 2003 page 1–2

on this path. Following this path can lead to understanding of life and its coming to be. What makes Hegel's theory strong is that he provides one coherent and continuous developmental path from the very beginning, space and time, to the very end, i.e., humanity. Several contemporary chemists are seeking to discover the minimal model system of life by arguing that the way to understand the gap between the living and the non-living is to recognize the continuity and the unified principle which underlies both. These theories, regardless of their specific focus, presuppose the structure and methodology Hegel puts forward. Moreover, the scientific facts they invoke add more details to Hegel's principle.

Through the development of science, it has been questioned whether science is sufficient to solve the mystery of life. In our time, there is no difficulty in identifying the material constituents of any living thing. We also have an understanding of how a self-renewing system is organized and becomes alive. There are philosophical discussions about what approach we should take to tackle this question. We should not be satisfied with enumerations of a list of characteristics. Aristotle and Kant tried to recognize a common pattern across the variety of different life forms. These days, scientists are generally satisfied with the pattern-recognition method of identifying life on Earth.<sup>119</sup> This assumes that there are certain characteristics or features that distinguish living from

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<sup>119</sup> They follow the reasoning that involves drawing general conclusions or predictions based on specific observations or evidence. It allows us to infer a general principle or hypothesis from a limited set of observations or experiences. Kant attempts to draw a general principle of life from his observations and experiences with plants. There are two major problems with induction: it does not provide absolute certainty in the conclusion. The conclusion is based upon the assumption that the past observations or evidence will be consistent with the future observations. This may lead to the "black swan" problem due to the limited account of observation. Another issue is that this conclusion relies on the assumptions that the observations can represent the entire group in consideration. This already assumes the existence of an individual group. For example, Kant's principle of life is limited to his experiences of plant life. It is questionable to what extent his principle can apply to other living forms, known to us, or unknown to us.

nonliving things. In scientific study the patterns are metabolism or replication.<sup>120</sup> Yet there is controversy about which of these two comes first, and also about what is being replicated. To resolve this conflict, many scientists nowadays try to create organic beings out of inorganic materials. However, there are still questions about what they should create: a system with replication or a system with metabolism or a system with both.

In his book *What is Life?*<sup>121</sup> Pross argues that there is one set of underlying rules that dictates both chemical processes and biological processes. There is one driving force operating through the whole process of the emergence of life. The apparent separation of chemical and biological processes is mainly because we have created two separate systems to describe chemistry and biology when our knowledge of them was limited. With all the advanced understanding in chemistry and biology, there is no difficulty for us in reconciling the underlying principle of these two systems and using a unified descriptive system to address both fields. Pross argues that life should be defined in terms of the processes and phenomena that sustain it, such as replication, metabolism, and evolution, rather than by identifying a single, defining property of living things. In the light of this strategy, we can easily address chemical processes in living beings under systematic chemistry, in principle and in experiments. Living system is a particular type of chemistry and no more than chemistry.

Attempting to close the gap between chemistry and biology, Pross's plan is similar to what Hegel does with chemistry and physics. As we discussed earlier, Hegel

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<sup>120</sup> The meaning of this will be discussed in detail later in this chapter.

<sup>121</sup> Pross 2012

suggests that the electromagnetic force is the underlying principle for all of physics, including machines and chemism in Hegel's concept. Although there is a boundary between physics and chemistry,<sup>122</sup> with this unified law, we can still clearly see the continuity between these two fields. Physics studies the laws that govern matter and energy. It studies force, motion, energy and properties of electromagnetic particles. The subject of physics ranges from subatomic particles to large scale phenomena such as astrophysics. Chemistry works with similar contents of things in a smaller scale – it studies the force, motions, energy and properties of atoms and molecules during their interactions. The main difference between physical and chemical reactions is the fact that only the latter involves forming and breaking of chemical bonds, where the change of chemical bonds can be explained by the electromagnetic forces between electrons in molecules. Hegel is aware of this, claiming that there is a continuity between chemistry and biology. Although Hegel's understanding of detailed scientific fact is limited by the available knowledge during his era, his overall understanding of nature gives him the confidence to claim this continuity between physics and chemistry: his theory suggests that chemistry presupposes everything that came before it in the developmental processes, i.e., light, magnetism, electricity, and so on. Pross suggests that current chemistry enables us to use a unified law and language to describe biology, in the same way that we can use physics to describe chemistry. With a well established continuity between chemistry and biology, Pross suggests, we can easily tackle most of the

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<sup>122</sup> In contemporary science, Chemistry is separated from Physics. Physics is no longer an overarching concept including chemistry and some other processes. This is different from what Hegel does.

challenges we are facing in understanding life.<sup>123</sup> Aside from developing his argument based upon his research in chemistry, he also brings in the idea of dynamic stability along with the Second Law of thermodynamics to answer the famous question asked by Schrödinger—“how could far-from-equilibrium systems have emerged naturally?”

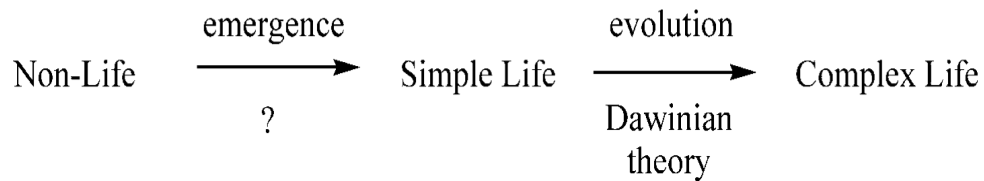


Fig. 1<sup>124</sup>

Pross uses the flow chart above to explain the problem we face in trying to understand the concept of life. We recognize two parts of the developmental processes from the non-life stage to the complex life stage, namely from non-life to simple life, and from simple life to complex life. Simple life<sup>125</sup> is the minimal form of life which is distinct from non-living processes before it. The reason why we divide it into these two parts is that we seem to have a comprehensive understanding of the second half of the development – the Darwinian theory of evolution can give a well accepted objective explanation of the development from simple life to complex life. Yet the same theory seems unable to account for the first half, so it natural to divide them.

<sup>123</sup> In Pross's own words "thanks to recent findings in systems chemistry, the origin of life problem, at least in its ahistoric sense, may be largely resolved" (Pross 2012, page 182).

<sup>124</sup> Figure 1, (Pross 2012, page 126)

<sup>125</sup> There is no generally agreed definition of what this simple life should be. Two popular theories are systems which can replicate themselves, and systems which are maintained by metabolism. To make this chart work, simple life here must be, on the one hand different from non-life, and on the other hand, able to participate in Darwinian evolution. We will address Pross's understanding of this later. We should be aware that in Pross's theory, what this simple life is does not matter, because he believes this question only exists because we do not yet understand the whole development.

Accepting the Darwinian theory of evolution, we have a clear objective understanding of the development from simple life to complex life. The other development is from the non-life stage to the simple life stage. This non-life stage is what we consider as the chemical phase. The task of understanding life, according to Pross, is essentially looking for a theory to explain what has happened in the process whereby non-life becomes simple life. We generally believe that the two stages, i.e., the chemical and biological stages, are somehow separated from each other in a way that either they follow different principles or there are different driving forces behind them. This suggests that although the precise boundary between them is still controversial, the differences between these two stages seems clear in science. The study of what is life places heavy emphasis on how to bridge the gap between these two subjects: is there some special instance that transfers chemistry to biology? Hegel suggests chemical processes can automatically form systems with an accidental self-maintaining function.

Pross takes a different approach. He argues that the current dichotomy of chemistry and biology is created by the fact that scientists use two different sets of languages to address each one of them. On the one hand, he argues there should be one unified underlying principle which dictates the whole development from non-life to complex life as shown in Fig.1 above. On the other hand, Pross believes one possible unified principle can be the natural tendency of increasing complexity. To prove this view, Pross enumerates how we can describe many processes in chemistry with biological terms, and vice-versa. He points out that the well accepted natural selection principle is a mechanism with the purpose to increase the level of complexity in the

whole system. This suggests that the seemingly reasonable boundary between chemistry and biology does not have a solid existence – it is an imaginary boundary which is created for practical reasons. Pross offers an alternative explanation to address the differences between chemistry and biology: there are only normal chemistry and replicative chemistry, where the first is governed by the Second Law of Thermodynamics and the second by the laws of replicative chemistry (replicating molecules). Biology is merely, in Pross's version, a branch of chemistry, with a different mechanism – not the mechanics of how chemicals interact with each other, but how chemical processes interact with and depend upon each other.

#### 4.3.2 Contradiction with the Second Law of the Thermodynamics

One problem with the emergence of life is that it appears to contradict the Second Law of Thermodynamics. The Second Law of Thermodynamics states that the total entropy, or the degree of disorder, of a closed system will tend to increase over time. This law states that in any process, some energy will be wasted as unusable heat and that the total amount of usable energy in the system will decrease. In the context of life, the Second Law of Thermodynamics poses a problem because life is characterized by ordered structures and processes that require a continuous flow of energy to maintain their order. This is in opposition to what the Second Law dictates, because life creates more ordered systems from less ordered ones. However, living systems are able to maintain their order by continuously taking in energy from their environment and using it to perform organic functions. This allows them to temporarily defy the tendency towards disorder that is predicted by the Second Law. One example to demonstrate this is that a car with no energy will only go downhill following the Second Law of

Thermodynamics; yet a car can use energy to go uphill, which appears to contradict this law as it is moving towards a less stable state. Pross points out that this is a form of non-equilibrium thermodynamics.<sup>126</sup> The non-equilibrium thermodynamic approach to life is a theoretical framework that seeks to understand the behavior of living systems as systems that are out of thermal equilibrium, meaning that they are not in a state of maximum entropy. In traditional thermodynamics, directly following the Second Law, a system is considered to be in thermal equilibrium when it has reached a state of maximum entropy, or disorder, and there is no further energy available for work. However, living systems are inherently non-equilibrium systems because they maintain a constant flow of energy and matter, and they display organized structures and processes that are not typical of thermodynamically balanced systems. This model provides a framework for understanding the behavior of living systems by considering their non-equilibrium behavior as a result of their ability to extract and dissipate energy from their environment. In this view, living systems are complex networks of energy and matter fluxes that are maintained by the constant exchange of energy and matter with their environment. Fountains and waterfalls are two examples of the non-equilibrium thermodynamics system. It is the formation of their system, not their materials, that defines what they are. They take energy from outside, electrical energy and potential energy respectively, to stay in a state in which their constitutive matters exhibit the increase in order.

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<sup>126</sup> Pross 2012, page 118

Such a non-equilibrium system is known as a “dissipative structure”.<sup>127</sup>

“Dissipative structure” is the term used in the field of non-equilibrium thermodynamics to describe a system that is maintained by a continuous flow of matter and energy from its environment. The term "dissipative" refers to the fact that the system loses energy to its environment in the form of heat, and that this loss of energy is essential for the system's stability and persistence. This structure is a complex, organized system that can persist only as long as it receives a constant input of energy and matter. One example Pross uses is the draining of water in the bathtub. When you unplug it, the water swirling down forms a structure which is more structured than before. A more ordered structure seems to appear from a less ordered one, spontaneously. Yet the water, as a whole system, is consuming potential energy, previously stored in the water, to create and maintain this order. Once the potential energy is used up, without further energy input, the system loses its order.

The problem of life and entropy itself is rooted in a misunderstanding of the Second Law of Thermodynamics. The problem arises when we assume that entropy is the same as disorder. Back in the time when Rudolf Clausius proposed the concept of entropy in the 19th century, he noted that entropy is related to both the energy flow and the order in the system.<sup>128</sup> In the 19th century, in the field of statistical mechanics, Ludwig Boltzmann developed Boltzmann’s Equation from his entropy experiment.<sup>129</sup> Boltzmann’s equation tells us that although we use entropy to indicate the level of

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<sup>127</sup> Pross 2012, page 118

<sup>128</sup> <https://plato.stanford.edu/entries/hermann-helmholtz/>

<sup>129</sup> [https://en.wikipedia.org/wiki/Boltzmann\\_equation](https://en.wikipedia.org/wiki/Boltzmann_equation)

disorder of a system, entropy also measures the energy produced by the system in a changing process. It is a common mistake to think disorder equals entropy exclusively. The actual concept is much more complicated than this since order itself is closely related to energy. The emergence of a star is a good example to show how energy change plays a significant role when we talk about entropy. Stars are formed from clouds of scattered dust. It was the gravitational force among them that made them collapse together to form the stars. The system is less ordered at the beginning than at the end. This increase of entropy comes with an enormous energy change in the system<sup>130</sup>: a significant amount of energy was created due to the collapse and excessive heat emitted by radiation. Gravitational force brought the system into a more ordered state at first. Then nuclear reactions kept the system in this higher ordered form. Therefore the energy the system captured was potential energy and nuclear energy. The mistake of identifying entropy as disorder may be due to the fact that heat energy is often identified with change of orderliness.

In the discussion of the emergence of life, there are two challenges posed by the Second Law of Thermodynamics: on the one hand, the question as to how such a non-equilibrium system can be fully addressed by our physical and chemical knowledge; and on the other hand, how such an ordered system can emerge from a less ordered system. When we look at the Second Law of thermodynamics in a bigger framework, the conservation of energy, i.e., not only with orderliness, but also with energy change, the problems are solved smoothly. It does not contradict the Second Law when living beings, i.e., more ordered ones, emerge from, and exist in, a less ordered inorganic

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<sup>130</sup> <https://science.nasa.gov/astrophysics/focus-areas/how-do-stars-form-and-evolve>

world. This change consumes energy from its external environment to compensate for the energy needed to create order from chaos – in an overall picture, the change still follows the Second Law of Thermodynamics as energy still flows from an environment with more energy to an individual system with less energy. This suggests that the decrease of entropy only happens spontaneously if the system consumes some energy, either from outside or inside itself, or both. Indeed we saw that ordered systems can only emerge when there is energy flow in the process, yet it is not necessary that such energy is generated by the ordered system itself. Bringing the idea of dissipative structure into this discussion, Pross seems to suggest that such an ordered living system could emerge and be maintained, to a certain extent, by consuming mechanical or chemical energy from the outside.<sup>131</sup>

Before looking at Pross's discussion of the autocatalytic system, there are two things we need to know. First, Pross's research only focuses on finding an ahistorical principle – a principle that can explain why matter of any kind would tend to increase in complexity, tending the direction of biology. This study does not concern the time and place of the emergence of life as a natural historical approach does. A natural historical approach prioritizes the understanding of plausible mechanisms for the emergence of life over the actual principle governing biological complexification. Pross believes that as we have such limited knowledge about the pre-biology world and as natural history cannot repeat itself, the only search that can address our current confusion is the

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<sup>131</sup> The relation between the dissipative structure and life are discussed in Pross 2021 pages 117 and 118. The physical principle behind it is discussed in detail in another paper "On the Emergence of Autonomous Chemical Systems through Dissipation Kinetics" (Pross and Pascal 2023).

ahistorical approach.<sup>132</sup> Second, Pross wants to show that there must exist one principle that can explain the whole development from inorganic materials to advanced life forms. and that principle must be based upon dynamic kinetic stability that could work as a “conceptual bridge”<sup>133</sup> between biology and chemistry. Once we have this sub-branch of stability in place, there should be no difficulty in identifying the unified underlying principle that powers the changes in chemistry and biology in the same way. Identifying this unified underlying principle is the aim of an ahistorical approach to the question, *What is life?*

Pross, like many other scientists,<sup>134</sup> points out that the key to answering the question *What is life?* lies in what form of answer we are seeking. Pross suggests that the question *What is life?* can be satisfactorily resolved through “a fundamentally reductionist approach—by seeking the underlying connections between chemistry and biology, by identifying the process responsible for biological complexification” (Pross 2012, page 57). In his view, life is an emergent property that comes from very complex chemical interactions.

#### 4.3.3 The Nature of Two Different Stabilities

Pross believes that two fundamentally different kinds of stability lead to the existence of two material worlds—chemical and biological. He points out that there is the stability, as we normally understand it, associated with low level changes.<sup>135</sup> The

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<sup>132</sup> Pross 2012, page 87

<sup>133</sup> Pross makes this point clear in his paper “Dynamic Kinetic Stability as a Conceptual Bridge Linking Chemistry to Biology” (Pross 2013). More details about this will be discussed later in this section.

<sup>134</sup> For example, Ganti 2003 and Tirard et al. 2010

<sup>135</sup> Pross 2012, page 75

driving force behind this is that all objects and systems have the tendency to settle into a low energy status. In chemistry, which is the lack of reactivity. Pross suggests another stability which is related to maintaining a factor's physical presence in the world and which applies to replicating systems of all kinds, regardless of whether those systems are chemical or biological. This stability only works at the population level: it is the replicator population as a whole that can exhibit this stability. This second kind of stability is dynamic kinetic stability.

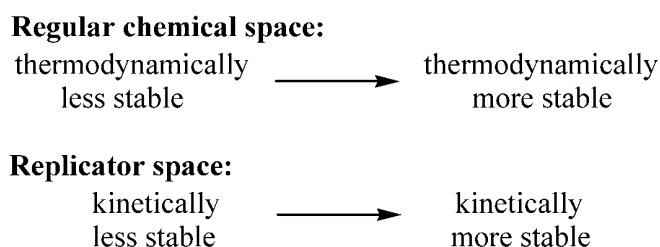
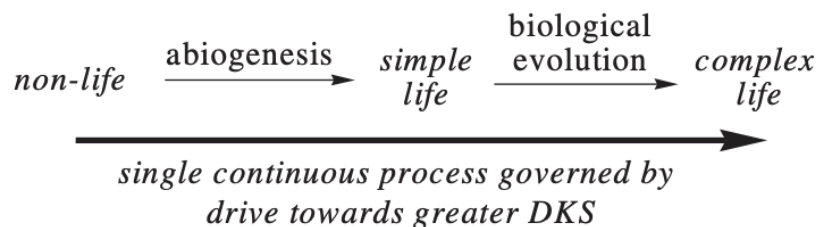
Dynamic kinetic stability refers to the ability of a system, typically a chemical system, to maintain its structural integrity and function, far from equilibrium through continuous energy input and dissipation. It is the ability of a system to remain stable and perform its function in the face of environmental changes, such as changes in temperature, pH, or other external factors. This stability is essential for a system to persist and exhibit dynamic behaviors, such as self-organization and evolution. This stability is rooted in populations rather than individuals.<sup>136</sup> There is a constant turnover of individual objects in populations and the environment external to the population is constantly changing, whether the change is caused by the replicator or by something else. This stability cannot be precisely quantified in the same way that ordinary stability can be because of this constant alternation. However, we do have two indicators that could give us a rough idea of how stable a system is. According to Pross, one relatively reliable indicator is the period of time the system has survived. This is a practical measure of the system's stability. Cyanobacteria, which have continuously existed for 3.5 billion years, are considered highly stable. The other indicator is the population size

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<sup>136</sup> Pross 2012, page 144

of the replicator at a given time. We consider cockroaches, with a large population, to have a greater Dynamic Kinetic Stability than pandas, in our time.

Having established this, Pross moves forward to claim that “nature’s basic selection rule is the same in both worlds: systems tend to be transformed from less stable to more stable”.<sup>137</sup> Pross believes this is the unified principle underlying both the chemical and biological world. The driving force behind regular chemical reactions and Darwinian selection is the natural tendency that every system will move to a more stable status.

Fig. 2<sup>138</sup>Fig. 3<sup>139</sup>

As a chemist and biologist, Pross gives several examples in his book,<sup>140</sup> and has published papers to show how those chemical or biological mechanisms can be

<sup>137</sup> Pross 2009, page 8376

<sup>138</sup> Pross 2009, page 8377

<sup>139</sup> Pross 2013, page 1702

<sup>140</sup> Pross 2012, Chapter 7: Biology is Chemistry

explained in terms of their tendency to pursue stability, either the kinetic stability or the thermodynamic one.<sup>141</sup>

One central example Pross uses in this discussion is the mechanism in the replication of RNA in Von Kiedrowski's experiments. Von Kiedrowski's experiments focused on the creation of simple chemical systems that could replicate themselves through chemical reactions. These experiments aimed to demonstrate that self-replication could be achieved without the need for a biological organism. In the experiments, he not only creates the replicating system from inorganic materials, he also captures the mechanism of changes that happen in the replications of RNA molecules. These two aspects cover both areas of biology, i.e., functional biology and evolutionary biology.<sup>142</sup> Pross suggests that the replicating procedure in these RNA experiments indicates that replication drives toward greater dynamic kinetic stability. In Pross's paper 2013,<sup>143</sup> he uses Fig. 3<sup>144</sup> to demonstrate the idea that one unified principle underlies the processes before and after life emerges. However, this figure misses one important point which Pross emphasizes in his discussion of the dynamic kinetic stability — there are two types of stability which are pursued in ordinary

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<sup>141</sup> I have no knowledge to evaluate the accuracy of these substituted explanations. I will take them as reliable at this point, then evaluate the strategy he uses. One question is if these transitions are merely semantic, or if they signify some concrete continuity between chemistry and biology. The other question is that even if these examples are solid, are they sufficient to draw his conclusion about the continuity between chemistry and biology? If they are not, what would be sufficient to arrive at such a conclusion? In addition, even if there is a principle that can explain both chemistry and biology, is it sufficient to explain what happens at the interface?

<sup>142</sup> Pross talks about the division in detail in his 2009 paper "The origin of life: what we know, what we can know and what we will never know" (Pross and Pascal 2013) .

<sup>143</sup> Pross and Pascal 2013, page 3

<sup>144</sup> Abiogenesis refers to the process by which life arises from non-living matter, in contrast to biogenesis, which is the process whereby living organisms only arise from other living organisms. Abiogenesis is a central aspect of the origin of life (OOL) question, which seeks to understand how life emerged on Earth from inanimate matter.

chemistry, i.e., before replication, and in biology, i.e., replicating chemistry, respectively. Fig.3 shows the unified driving principle. If we correct our original understanding of the Second Law of Thermodynamics according to his proposal, where there are two separate stabilities in the two segments, then we need to ask what can guarantee the continuity between the two stabilities. There are two criticisms Pross has to answer: Is the similarity between chemistry and biology created merely by semantic manipulation? And second, Even if the correspondence between the one stability and its corresponding field in chemistry is solid, does this give us any information about how traditional chemistry becomes replicating systematic chemistry, or about what makes the system start to pursue the new type of stability?

We should not be surprised if there exists a set of processes that works well in describing both chemistry and biology. This is rooted in the methodology we use in biology. We use our knowledge of chemistry to comprehend biology, in the same way that we use physics to understand chemistry. So no matter how many similarities Pross, and other scientists, can enumerate, the only question we are concerned with in this discussion is whether or not the same set of principles can explain the aspect which makes biology different from chemistry, for example, why reactions in biology pursue dynamic kinetic stability, but not merely the thermodynamic stability which is pursued by other chemical reactions. It appears that Pross does not plan to examine this in his further research, since he believes that replicating system chemistry<sup>145</sup> naturally pursues dynamic kinetic stability in the same way reactions in ordinary chemistry pursue

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<sup>145</sup> Replicating system chemistry in Pross' discussion refers to the chemistry of a replicating system that exhibits dynamic kinetic stability (Pross 2012, page 75). Replicating system chemistry is distinct from traditional chemistry for its unique characteristics and behaviors of replicating entities that drive their evolution.

thermodynamic stability. Both of them happen, according to the same natural laws, in exactly the same way – there is nothing extra to be explained in this change. To explain how ordinary chemistry becomes replicating system chemistry, Pross brings in the difference between historical and ahistorical explanations. While historical explanations focus on the specific events and circumstances that led to the emergence of life on Earth, ahistorical explanations focus on the underlying principles and processes that govern the behavior of all systems, regardless of their history. Historical explanations look back in time and attempt to reconstruct the sequence of events that led to the first living organisms. Historical explanations are based on observations and data from the natural world and involve, as used in our current inquiry into the origin of life,<sup>146</sup> a significant degree of speculation and inference. On the other hand, ahistorical explanations focus on the underlying principles and processes that govern the behavior of living and non-living systems. These explanations are not tied to specific events or circumstances but seek to uncover the fundamental principles that underlie the behavior of all systems, regardless of their origin or history. Pross suggests that we can make up many historical explanations of the emergence of life when no one can provide any counter-evidence, since there is almost no evidence covering that transition. He argues that ahistorical explanations on the other hand are more fundamental and informative than historical explanations because they focus on the principles and processes that apply to all systems, rather than just one particular system. Ahistorical explanations can

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<sup>146</sup> We can find some traces of evolution in the natural world, e.g., fossils. Yet we cannot find any evidence of the particular emergence of, in his words, replicating system chemistry. Therefore, the historical explanation of the origin of life will develop from speculations and inference exclusively.

help us understand the basic principles that govern the behavior of living and non-living systems, and how these principles can lead to the emergence of life.<sup>147</sup>

Therefore, Pross only works on finding ahistorical explanations for our current topic, which is to propose a unified underlying principle.

In Pross's 2013<sup>148</sup> paper, he tries to clarify what we know about the emergence of life without his theory, what we know about it if we accept his theory, and what requires more study in the future. He tries to strengthen his theory by making an analogy between his proposal, that there is a unified theory underlying both chemistry and biology, to Darwin's theory of evolution. They are the same in the sense that they "specify the essence of the ahistoric principles by which that process came about (Pross and Pascal 2023, page 5)". Presenting itself as a hypothesis at the beginning, Darwin's theory not only successfully pointed to the right direction for biological research, but also gained more followers who continued study in the field, and will be adding more historical evidence to this ahistorical theory. Putting himself in the same position as Darwin, Pross must face the logical barrier that such a hypothesis can only be proved wrong, but never be proved right. Even though the theory of evolution dominates its field of study in our time, there are still strong critics who could sabotage the theory because there is no way to prove it right. That is to say, Pross only proposes this model as a possible perspective in the inquiry into the origin of life. His theory gains much support among those who work at the interface of chemistry and biology, yet it is likely to take quite a while to gain the dominant position that evolution theory has attained or to be

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<sup>147</sup> In this particular research, Pross suggests, we do not really have a choice because there is no evidence from the time life emerged.

<sup>148</sup> Pross 2013

disproved. However, we can tell that his theory may not provide insight into what makes the processes begin the pursuit of dynamic kinetic stability instead of thermodynamic stability, since these two stabilities are still incompatible with each other in terms of the stability they pursue: their aims are not unified yet. Pross cannot answer questions such as "what is the driving force behind this transition?" and "is such change necessitated by the unified principle proposed?"

Working at the interface of chemistry and biology, Pross also presents several discussions about the minimal life form. It appears that his original plan is to place most of the emphasis on the unified underlying law and ignore detailed discussions of what is the minimal form of life. In his plan, having the unified underlying law established, the minimal form of life is only one detail, like all other details, that we need to fill in.

However, even if he can have such a law established, he still needs to take care of this discussion separately, maybe from a different angle.<sup>149</sup> In a paper published in 2013, Pross clearly states that, in the debate on the origins of life, "there is one single and central historical fact on which there is broad agreement — that life's emergence was initiated by some autocatalytic chemical system" (Pross 2012, page 2).<sup>150</sup> An

autocatalytic chemical system is a self-sustaining chemical system in which a particular chemical reaction catalyzes its own production. In other words, the products of the

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<sup>149</sup> He needs to answer questions such as when and why the same system starts to pursue a different type of stability and whether or not it is necessary to have Dynamic Kinetic Stability on top of thermodynamic stability. Answering these questions requires a concept of the minimal form of life.

<sup>150</sup> He also mentions that living systems can be distinguished from the others by their ability to carry out two essential functions: metabolism and replication. (Because his theories are developed upon experiments of replication, we know that his study only concerns groups of living systems instead of individual living things.) He mentions this controversy of metabolism first as opposed to replication. He thinks his proposal of a unified underlying principle can resolve this conflict to a significant extent so he does not take a stand. Yet in his discussions, we will see as we go on, he shows his preference for replication first.

reaction serve as catalysts for the reaction to occur again, creating a positive feedback loop that allows the reaction to continue.

In Hegel's theory, chemical processes become alive when they realize self-sustaining characteristics. The purpose comes into being in this self-sustaining function. The end of this purpose is to maintain the chemical processes themselves. As discussed earlier, one way to realize this self-sustaining function is to produce the same group of chemical reactions with which the process began.<sup>151</sup> The autocatalytic chemical systems go one step further than this by also maintaining the reasonable speed of the reactions. Pross cites the replication of RNA as an example of an autocatalytic reaction.<sup>152</sup> The hypothesis of taking RNA replication as the minimum form of life is first proposed by Walter Gilbert in his paper 'The RNA world' 1986.<sup>153</sup> In this paper, Gilbert analyzes new laboratory results to suggest that RNA molecules could have catalyzed essential biochemical reactions in early self-replicating systems, eliminating the need for protein enzymes at this stage.<sup>154</sup> That is to say RNA is capable of acting as both the template for its own replication and as the catalyst for the chemical reactions involved in replication. This means that as RNA molecules replicate, they also catalyze the formation of more RNA molecules, leading to an exponential increase in the number of RNA molecules over time. It is generally believed that the autocatalytic nature of the RNA replication will lead to the emergence of self-sustaining chemical

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<sup>151</sup> When the self-sustaining system really formed, it would be impossible to say what is the beginning and what is the end of the group of reactions. Metaphorically, it is more like a circle. When I say the beginning and the end, I am pointing to the moment before the reactions close the circle.

<sup>152</sup> Pross 2012, page 65-67

<sup>153</sup> Gilbert 1986

<sup>154</sup> Gilbert 1986, page 1

reactions. There are mechanisms in these replication processes which would enable the system to grow increasingly complex while pursuing Dynamic Kinetic Stability. Over time, RNA molecules may have evolved the ability to catalyze more complex chemical reactions and to carry out other functions that would otherwise be performed by proteins in cells. (Joyce 2002 provides significant details of the experiments on RNA replications and their evolution).<sup>155</sup>

The focus of an autocatalytic chemical system is a replication reaction with the tendency to increase its dynamic stability. I want to point out that Pross clearly states that “the essence of life will be found to lie in the dramatic difference between the rates of catalytic and autocatalytic reactions” (Pross 2012, page 63). Unlike catalytic reactions, autocatalytic ones can produce the catalyst for themselves to increase the speed at which the reactions happen. By doing this, they actualize a kind of self-sustainability which is different from the one discussed earlier.

Pross explains why chemical processes could happen and how catalysts work in the light of thermodynamic considerations. All chemical reactions involving one or more materials become one or more different materials. According to the Second Law of Thermodynamics,<sup>156</sup> reactions happen in the direction where the stability level decreases. Less stable materials, on the other hand, become more stable materials in chemical processes. Taking the reaction between oxygen and hydrogen as an example,

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<sup>155</sup> In the past few years, since 2013, when Pross' paper was published, many biologists and chemists have been working on the replication of RNA in the hope of figuring out a possible mechanism for the emergence of self-replicating systems in prebiotic environments. According to a study published in 2020 by a team of researchers led by Jack W. Szostak at Harvard University, scientists are very optimistic about determining these mechanics in the lab (Li et al. 2017).

<sup>156</sup> One simple statement of the law is that heat always moves from hotter objects to colder objects, unless energy in some form is supplied to reverse the direction of heat flow.

water is more stable than oxygen and hydrogen in their separated gaseous states. The reaction of oxygen and hydrogen, resulting in water, is easily engendered with a spark or metal catalysts; yet the reverse reaction is much harder since what is produced is less stable than the materials before the process. Although the first reaction, gasses to water, happens more easily, catalysts or extra energy are still required to initiate the reaction. One way to understand this is that some energy is required to break the atomic structure<sup>157</sup> of oxygen and hydrogen before they can be recombined in a more stable form, i.e., water. Without overcoming this small energy barrier,<sup>158</sup> the reaction won't happen even though the whole reaction is in the direction encouraged by the Second Law of Thermodynamics. Without catalysts, most of the reactions either cannot happen, or happen at an extremely slow rate.<sup>159</sup> So a different type of self-sustaining reaction, as addressed by Pross and several others, constantly produces catalysts, which is necessary for the reactions to carry on at a “demanding” speed.<sup>160</sup>

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<sup>157</sup> In Hegel's theory, this structure is the shape of a material which determines the chemical characteristics of the material. External energy is required to break the existing shape, otherwise, it will keep holding itself in the same state because it must be a stable state for this combination – otherwise it would not exist.

<sup>158</sup> Though for some reactions, the barrier is not so small it is as they require a significant amount of energy to break the original atomic structure.

<sup>159</sup> Pross makes this claim in his book. However, there are many reactions that can happen without catalysts. For example, the reaction between sodium metal (Na) and chlorine gas (Cl<sub>2</sub>) to form sodium chloride (NaCl) is a chemical reaction that does not require a catalyst. The reaction occurs spontaneously when the two reactants are brought into contact with each other. In this reaction, the highly reactive sodium metal reacts with the highly reactive chlorine gas to form the more stable compound sodium chloride. No catalyst is required for this reaction to occur, as the reaction proceeds naturally due to the inherent reactivity of the reactants. There does not appear to be any criticism of the theory addressing this point, which seems to carry a lot of weight in his theory because if the reactions can happen without catalysts, merely being “extremely slow” should not be an issue for nature since she has plenty of time. Since this theory has been examined by many scientists, I would assume there is justification for the claim that this is true. Probably, catalysts are essential for almost all the reactions in the organic realm.

<sup>160</sup> In this context, “the demanding speed” is the speed of chemical reactions at which the living organism can stay alive. If the reaction is too slow, the nutrition supply may not be enough to keep the organism alive.

Pross also points out that there must be two kinds of chemical reactions where one is the reverse of the other. This is the same as the decomposition and composition Hegel discusses. Yet in Pross's version of the self-sustaining reaction, the necessity of this is brought in from a different perspective. In Pross's argument, the self-sustaining function is rooted in the ability of the system to assimilate materials from outside the system to maintain this ability of assimilation. The key in such reactions is combination.<sup>161</sup> In the completely closed systems, both combination and decomposition are required for the system to come back to the "starting point".<sup>162</sup> In this case, where there may be only combinations without decomposition, the system can still be closed because the system does not wait to use its own products to carry on the process. Yet there is another factor in this system that dictates the existence of decomposition. The primary reaction Pross addresses is molecular replications. In his theory, these replications, because they involve autocatalysts, exhibit exponential growth (Pross 2012, page 72). Without any kind of decay, this process cannot be sustainable because, Pross argues, its reaction will soon use up all the material on Earth. He points out that

"if one single molecule were to replicate 160 times it would (only in principle, of course) devour resources equal to the entire mass of the earth... In order for the replication reaction to be maintained for any

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<sup>161</sup> In a real-life situation, there are decompositions as well as composition since almost all the material from the outside must be decomposed before being assimilated into the system. Yet it is not necessarily the case since some systems can assimilate pure chemicals without decomposing them. So although decomposition at this stage is extremely common, its existence is not logically necessary. Its necessity emerged for a different reason which follows below.

<sup>162</sup> There is no genuine starting point in such systems since the whole system comes to be simultaneously, otherwise the function would not exist. I use the word "starting point" here in order to emphasize that all the reactions form a closed loop in such a system.

extended period, the replicating system has to decay at a rate that is commensurate with its rate of formation.” (Pross 2012, page 72)

Following Pross’s discussion, we can picture a living being as a machine sucking materials from the surroundings then combining them to form something new, as both part of the machine and as something else. The unprocessed materials will be exhausted, sooner or later, if products cannot return to the original form by decomposing.

This argument is not by itself sufficient to necessitate the existence of decomposition. Pross’s discussion of self-sustaining systems focuses on the idea that such a system has to sustain itself eternally: if there is no decomposition, the system cannot run forever although it can sustain itself before exhausting all the available materials. Therefore, there must be decomposition, which is the inverse reaction of composition. Faced with Pross’s argument, we should examine the role of eternity in this discussion: Does eternity play an important role in a living being? If it is an essential characteristic of living beings, then Pross’s argument, resting on this ground, may sound plausible. Indeed, the word self-sustainable carries a default characteristic of eternity, in principle; yet it should only be in principle. In the discussion of life, eternity should never be in the picture. There are pre-life periods on the Earth. There is no reason to assume that there could not be another non-life period on Earth in the long term future. On the one hand, disasters,<sup>163</sup> such as irregular solar activities or falling aerolites from outer space could possibly eliminate life from the Earth. On the other hand, almost all the so-called self-sustaining systems are not eternal because of the limited efficiency with

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<sup>163</sup> We call them disasters only because they are fatal for us, as well as to other living beings on the Earth. For the natural world itself, they are merely plain physical activities.

which they maintain themselves and due to the restrictions of the amount of raw material available. We currently inhabit a world with an apparently balanced rate of combination and decomposition. Yet in the long term, we still need to worry about the energy crisis. The suggestion is that in principle, we will exhaust all the materials we require to maintain life. In addition, the principle of heat death suggests that in the long term, all life in the universe will disappear. That is to say, in our current discussion, we should not require the characteristic of eternity for our self-sustaining system. All animal lives are limited, yet the fact that they will cease to be in the future, near or far, would not compromise their identity as a self-sustaining system. In Hegel's model of a self-sustaining reaction, the existence of decomposition is necessary; yet in the autocatalytic model, it is not the case. Another possible way to establish the necessity is to see if decomposition is necessary for RNA replication. In a 2014 paper, 'Molecular Biology of the Cell', several biologists demonstrate the replication of RNA in detail. According to this paper, RNA replication typically does not involve decomposition, as it is a process of creating a new RNA molecule that is complementary to an existing RNA molecule. Instead of breaking down a molecule, RNA replication involves the synthesis of a new molecule using a template. In some particular cases, RNA molecules can undergo decomposition, yet decomposition is not necessary for RNA replication<sup>164</sup>

Kauffman's book, *The Origins of Order: Self-Organization and Selection in Evolution*,<sup>165</sup> is one of the earliest to suggest that an autocatalytic set of molecules is the minimal form of life. He suggests that these sets could undergo evolution and exhibit

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<sup>164</sup> Alberts et al. 2002

<sup>165</sup> Kauffman 1992

properties similar to those of living systems, such as metabolism, growth, reproduction.<sup>166</sup> Ever since this theory has been known, many studies and experiments have been carried out to support it.<sup>167</sup> Below are some of the most recent major ones.<sup>168</sup>

#### 1. The ability to create and maintain self-organization.

Autocatalytic systems exhibit self-organization, which is a fundamental characteristic of living systems.<sup>169</sup> The ability to maintain this organized structure has been the focus of many early studies. Aristotle does not address this in his theory, yet Kant and Hegel, as philosophers who are interested in what goes on under the skin, both emphasize this ability. They are aware that there is a special organization which is caused by and causes the existence of each living individual. As modern scientists consider the origin of life to be as important as the characteristics of life, they place

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<sup>166</sup> Eventually we will find that this is similar to our analogy between machines and lives except this analogy is more advanced, though the mechanism is the same. We started by identifying some particular characteristics, which are considered essential for life, in the system. Those characteristics came from our observations of living individuals. By arguing for how essential those characteristics are for life, and how strong the similarity between machines and lives is, some try to conclude this system is a model of life. By contrast, some others try to argue against this analogy by claiming either that some important features of life are missing in the system, or that the similarities are superficial. Maybe we need to reconsider this particular way of defining life. Or at least we should think about what is the standard for a system to be good enough in this strategy. One significant improvement in this analogy, compared with the one between life and machines, is that this analogy also emphasizes the coming into being of machines, and the path of evolving, whereas the old similarities are mostly about how the machine works at a particular time. However, the same mechanism underlying the strategy is still in place: this analogy is better because the similarities are about characteristics we now consider more essential for life: instead of self-moving, we more highly value self-emerging and self-evolving. Does this make the strategy better, or still the same?

<sup>167</sup> There were many important works of research and studies in early periods which are the foundations of much research today, such as Stuart Kauffman, Tibor Gánti and many others. However, since their studies are experiment-based, their theories have been improved significantly by later scientists following their original plan. Since most of these arguments are developed with experiments in laboratories, I try to limit resources to the last decades in the belief that the ability of our scientific experiments to unveil the truth accumulates over time: although there is controversy about how to approach the essence of life, scientists' ability to ascertain nuances of the material constituents of living organisms and understand each step in chemical reactions in living beings advances every day.

<sup>168</sup> Scientists have proposed many detailed findings, with specific names, from their experiments. Since this is not a dissertation focusing strictly on experiments in chemistry or biology, I will rearrange them into bigger groups to present them.

<sup>169</sup> Vaidya et al. 2012

great weight on how life comes to be. They seek to find a minimum form of life which fulfills dual tasks: maintaining its structure and creating that structure. One reason the autocatalytic system attracts so much attention is that the RNA replicating systems, as one type of autocatalytic system, not only exhibit many characteristics of life, but also have the ability to emerge from less well organized materials. One famous experiment that demonstrated the potential for RNA replicating systems to arise from inorganic materials was conducted by Dr. Jack Szostak and his colleagues in 2009.<sup>170</sup> The experiment investigated the possibility of RNA replication in a prebiotic environment. It demonstrated that a self-replicating RNA system could arise from inorganic materials, without the need for the complex biological machinery found in modern cells. Although the experiment did not provide a systematic explanation for the origins of life, it suggested a plausible pathway for the emergence of self-replicating systems in a prebiotic environment through a process of chemical evolution. Being able to emerge from inorganic materials is a new requirement in the current study. We must be aware of the distinctions between a historical explanation and an ahistorical one. Experiments in this field mostly try to provide possible pathways for such a jump from an inorganic world to an organic one.

There are scholars who argue that it is not necessary to know the origin of life in order to understand what life is. The key idea is that even if we find a possible pathway for organic beings to emerge from inorganic beings, there is no way for us to evaluate the pathway in a real world situation since our knowledge about that period of time is very limited. Therefore, it is more fruitful to seek for the fundamental principles behind

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<sup>170</sup> Szostak et al. 2001

the emergence of life that are independent of time and place, asking what are the physicochemical processes that could have transformed non-living matter to evolutionary developmental living systems with the ability to sustain themselves.<sup>171</sup>

## 2. Being stable in interactions.

This stability in interactions is the same as metabolism in our previous discussions, only with some more advanced details. Living systems maintain a steady-state by constantly exchanging matter and energy with their environment and by regulating their internal conditions. Autocatalytic systems are also capable of maintaining a steady-state and they can do so without the need for external regulation or control. Some scholars advanced this idea, calling it a dynamic behavior.<sup>172</sup> The suggestion is that the system has a dynamic response, such as adjusting its behavior and metabolic activities to changes in its environment, i.e., temperature, pH, or chemical constituents in the environment. Metabolism itself already involves having dynamic responses to the outer environment: the system will at least respond to the change in the quantity of the resources. Yet now we are looking for a more advanced adaptability of the system: it needs to adapt to the tendency of increasing complexity – adapting to the environment to fulfill the deeper requirement of increasing complexity. However, we still need to remember the job here is to find the minimal form of life, not similarities between life and the autocatalytic system. There must be fragile life forms which cannot survive even slight changes in the environment. Seeking the minimal requirements, we should drop all the advanced functions and conceive the form of life which is able to

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<sup>171</sup> Pross 2012, page 100

<sup>172</sup> Vaidya et al. 2012

maintain its identity in the interaction with the outer environment, i.e., having metabolism. The autocatalytic system has no problem meeting this requirement.

### 3. The ability to evolve.

Another important similarity between autocatalytic systems and life is the ability to evolve. There is research on RNA replication from 2012 which suggests that “networks of interacting molecules were more likely to develop and sustain life-like behavior”.<sup>173</sup> The paper suggests that autocatalytic reactions can undergo a kind of chemical mutation when facing challenges from their environment. These changes can be accumulated over time, which indicates that there is information passed through generations. Assuming all the experiment's conclusions are solid, we still need to ask if this is an essential characteristic of life. It might be the case that all life forms known to us exhibit the ability to evolve; however, this does not indicate that all living individuals are necessarily capable of evolving. The essence of evolution is accumulating changes in replication. Replication in the current discussion is similar to both growth and generation in Kant's and Hegel's discussions.<sup>174</sup> Although contemporary scientists place a lot of weight on the ability to evolve, replication is the irreplaceable core of these concerns. The ability to evolve is being able to self-modify in replications. According to the experiments above, there should be no problem for an autocatalytic system to exhibit the ability to replicate itself; it can do even better than that in a way – it has the ability to adjust its ability of replication through the processes of replication.

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<sup>173</sup> Vaidya et al. 2012, page 1

<sup>174</sup> In those earlier understandings, replication concerns reproduction – replicating individual living beings. However, in contemporary studies of evolution, replications focus more on the replication of cells, or other small units. In this sense, some replication is growth.

There are two questions we need to consider when we decide whether or not a model is an eligible minimal form of life: Does it include everything that is necessary? And does it exclude everything that is unnecessary, e.g., being rational? Arguments against taking the autocatalytic system as the minimal form of life involve: 1) uneasiness with some of its proponents' experimental results; and, 2) suspicion that there are important aspects of life that autocatalytic systems miss.

Some critics claim that their experiments<sup>175</sup> show different results, or suggest a different reading of the results. Stuart Kauffman, a theoretical biologist and complex systems researcher suggests that although autocatalytic systems play an important role in the emergence of life, they are not sufficient to be the minimal form of life.<sup>176</sup> He believes the most important aspects of life are the ability to evolve, and having metabolism. He believes that, on the one hand, although autocatalytic systems have some interactions with their surroundings, these interactions are in no way metabolism. On the other hand, the tendency to become more complex in autocatalytic systems is not the same as Darwinian evolution. Those systems may be able to generate energy through chemical reactions, yet they cannot have the same diversity of metabolic pathways as living systems do. In chapters 6 and 7, Kauffman argues that it is essential for life to have diversity of metabolic pathways, both at its emergence and in its maintenance. By metabolic pathway, he means a different way to extract energy from the environment for its own use. Multiple pathways enable living objects to be able to better adapt by having a better chance to obtain energy from different environments.

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<sup>175</sup> I will leave this debate to the scientists. This controversy is in no way the last, or the most important argument in the current topic.

<sup>176</sup> Kauffman 1992

This ability can also help avoid competition among organisms so that different species can coexist in the same environment. Having multiple metabolic pathways is also essential for evolution as the new metabolic paths emerge through mutation to better adapt to the environment. It is very improbable for the autocatalytic systems to have this important diversity of metabolic pathways because such mutation is truism. Without such diversity, the system can hardly maintain itself in the ever changing environment.

Another critique focuses on biological reproduction. Being able to reproduce is an essential aspect of life and reproduction requires a bio-individuality that autocatalytic systems do not exhibit. An autocatalytic system can grow by taking energy and materials from the outside, yet there is no organic unity that can be reproduced in this self-maintenance process.<sup>177</sup> Since the stabilization of life on Earth now, no life need arises directly from inorganic things — each organism is generated by another living being (s). Yet some living beings do not have the ability to reproduce. This does not make them less alive. An autocatalytic system can be equally alive as a mule, which can live for a long time. If we imagine the first ever autocatalytic system, the original organism, lasting until now without regenerating another individualized copy of itself, is its system qualified as alive? Reproduction can be a very useful argument against most of the possible minimal forms of life since reproduction is unique<sup>178</sup> to living beings. Yet it seems not always pervasive because of the existence of non-reproductive living beings. So, we still need a separate set of defining characteristics of life, different from what Kant proposed to us, to evaluate different minimal forms of life.

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<sup>177</sup> This is an important aspect we need to consider in the following chapter about the Gaia Theory.

<sup>178</sup> The uniqueness of reproduction, in contrast to other forms of multiplication, were fully discussed in the Section about Kant.

There is no doubt that there are surprisingly significant similarities between autocatalytic systems and living beings, yet these may still be insufficient to qualify an autocatalytic system as any form of life at all. Amongst the many concrete similarities between life and autocatalytic systems, how many of those similarities are essential for being alive and how many of them are no more than analogies between the work of machines and metabolism in life? Aristotle considers tools and machines as ensouled objects, meaning that they are animated inanimates. For people before Kant's time, it seemed reasonable to consider machines as exhibiting what were thought of as the essentials of life. René Descartes is one of the most famous supporters of the belief that animals were essentially complex machines.<sup>179</sup> Today, such analogies between machines and living things can hardly gain any support, not because we have a more sophisticated methodology, but because we are aware of more detailed functions in life: organs work together in a way different from how parts of machines do. We know those apparent similarities between machines and life are driven by very different underlying principles. The methods the scientists use to determine the minimal form of life and evaluate it today are not more advanced than in Hegel's time. The method is this: first, find the difference between organic and inorganic beings from our observations, then figure out which are the most essential characteristics that can separate organic beings from inorganic ones; Finally, try to find some chemical processes to explain those essential characteristics. As long as all those characteristics can be explained by the chemical system, this system is considered a minimal form of life. Therefore, at the

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<sup>179</sup> Descartes' famous "animal-machine" theory is based on his belief that animals are devoid of thought and consciousness. He does not directly discuss whether or not purely mechanical interactions are sufficient to account for the function of an animal body because his aim is to show animals do not have a capacity of thought. He equals animal behavior to mechanical operation for granted (Hatfield 2023).

center of this task of finding a minimal form of life lies the old challenge we have been facing: what are the essential characteristics of life? Without answering this, we can hardly compare one model with another and evaluate how good they are as models for life.<sup>180</sup>

For minimal forms of life, as we discussed earlier, reproduction and evolution are essential factors of life whereas replication and metabolism seem more basic. We find some life forms that do not exhibit reproduction or undergo evolution. We know there are living things that are infertile, e.g. mules, or, at least in our current theories, are “generated” from non-organic beings.<sup>181</sup> That is to say, if we take reproduction as one essential characteristic of living beings, then mules and infertile ants are not alive: although they both result from reproduction. It is also possible to consider that things produced by other living beings are alive – mules are alive because they are produced by other living beings through reproduction, although they cannot give birth to other living beings. This contradicts our understanding of the emergence of life. So reproduction is not one of the essential characteristics. The strategy being followed is first making a hypothesis, then if counterexamples are found, we deny the hypothesis. Following this strategy, scientists nailed down the most essential properties of life, replication and metabolism. Then there are discussions about which of these two came

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<sup>180</sup> Unless we have a system which can evolve from inorganic materials all the way to organic beings, one without any doubt such as a cell, or a flower, we can hardly arrive at an argument of what is a good model of life created in chemistry or physics.

<sup>181</sup> Some of the mainstream scientists, e.g. Pross, believe life comes from inorganic beings (theories we have discussed in this chapter all belong to this group of scientists). This suggests there were living forms which were not born, or generated from other living beings.

first at the origin of life: replication, or metabolism, or whether both of them emerge at the same time.<sup>182</sup>

Scholars involved in this controversy take two different approaches: to find evidence supporting their own side and try to find counterexamples or even only one example to devalue arguments on the other side. The latter strategy, disproving the opponents, focuses on finding living things that have one of the properties, metabolism or replication, but don't have the other. We can imagine these attempts are mostly done in laboratory settings as life forms we encountered outside the lab almost always have both replication and metabolism and for those primary life forms scientists study, they need lab settings to determine if these organisms have replication or metabolism.

Arguments for the replication-first hypothesis are, at this moment, mostly based on our understanding of how a self-replicating system can emerge from a simple set of molecules, specifically RNA molecules. Laboratory results suggest that RNA played an essential role in the early evolution of life because RNA molecules have the ability to catalyze the formation of the other RNA molecules indefinitely.<sup>183</sup> In the RNA replication system outlined by Pross, two discrete RNA molecules can start a sustainable replication system when they are involved in a cross-catalysis process.<sup>184</sup> RNA molecules can catalyze each other's formation to start an infinite replication with certain flexibilities in the replication which could lead to the emergence of replication of complex form – replication of the system as a whole instead of individual components replicating

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<sup>182</sup> The last one is considered a hybrid view.

<sup>183</sup> Pross 2013, page 148

<sup>184</sup> Pross 2013, page 133

themselves. These laboratory studies suggest that replication, without metabolism, can give rise to self-sustaining systems.

There are two major issues with these arguments.

1, Being a self-sustaining system is not sufficient to qualify as being alive. As discussed earlier in the discussion of the Belousov-Zhabotinsky reaction, living beings are only one particular kind of self-sustaining system. Living beings are self-sustaining systems that exchange materials with their environment. Then the problem becomes whether the RNA replication system can be qualified as alive without metabolism and if this replication can lead to metabolism.

2. Is a replication system already a metabolic system? The essence of RNA replication, as described by Pross, is to take material from the environment, then transform it to other RNA molecules where the newly produced RNA molecules will be involved in the same process in the future. The previous RNA molecules may or may not be able to join the future process. Once they are unable to participate in the replication system, they are automatically out of the system. In this sense, the RNA replication is metabolism itself. They are not two independent aspects that can be chosen from. Metabolism may or may not include replication, whereas replication is a particular way to assimilate things from the outside.

Proponents for metabolism-first try to show how important metabolism is for life and how likely it is for metabolism to occur in the prebiotic environment on Earth. One problem the metabolism-first theory has difficulty facing is the idea that metabolism can exist potentially. Tibor Ganti, a renowned biologist who worked in this field, suggests that things are not only classified as living and nonliving – there should be four classes:

1. Living
2. Potentially living but not dead<sup>185</sup> e.g. dormant seeds, spores.
3. Dead (irreversible change from a living to a non-living state)
4. Non-living

Today, we know that there are some states of living beings in which their metabolism stops completely. Do those examples suggest we could have living beings without metabolism, or should they be considered non-living? In our discussion of Kant, we mentioned that one of the important differences between living beings and machines is that machines can be turned on and off, whereas living beings cannot, i.e., once the object loses life, it is impossible to get it back.

We always need to keep in mind: that the discussion of which of the two came first concerns the origin of life, whereas which of the two is the essential characteristic of life concerns the definition of life. The difference is that finding the origin of life needs to explain the developmental pathway, whereas finding the essential characteristics of life may or may not take on this challenge.

How a metabolic system can evolve is also a significant challenge for this theory. The discussion of the autocatalytic system considers the idea that a system needs to have a certain complexity of metabolic pathways to adapt to and evolve on Earth. People use this point to challenge the autocatalytic system by suggesting that it can never reach that complexity. This problem is more serious for the metabolism-first argument. Without a replication mechanism, the system cannot pass down any genetic

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<sup>185</sup> Cryptobiosis or anabiosis is a metabolic state of life entered by an organism in response to adverse environmental conditions such as desiccation, freezing, and oxygen deficiency. Some organisms that are known to enter cryptobiosis include tardigrades, brine shrimp, and certain nematodes and rotifers.

information between generations. Therefore without replication we cannot explain how such a system can evolve and adapt over time, not to mention reach the required complexity.<sup>186</sup> There are two separate questions in this challenge. First Is evolution possible in a pure metabolic system without replication? Second, can such systems evolve far enough to reach that complexity? The second question can hardly be answered with certainty. On the one hand, there are many possibilities in evolutionary processes. Unexpected changes are what lead us to today. We cannot even foretell the life-path of a new-born baby, not to mention the evolutionary path of a primary life form. The main concern here is that if we should be able to explain everything in living systems by laws in chemistry and physics, we should also be able to explain their evolution with these laws. For example, when we explain the motion of one object completely with the laws of physics, we expect that we are able to predict any changes in the future, and the object's reaction to any external impacts. With this analogy in mind, we are likely to think that we should be able to predict how these metabolic systems will evolve, no matter if the change is caused by themselves or by external interventions, insofar as these systems are constituted exclusively by chemical reactions. These challenges are only viable with this assumption – without this assumption scientists will not have the illusion of being able to predict how complex the system could evolve to be.

The pathway of evolution is not as predictable as pure mechanical systems or chemical reactions. On the one hand, the external environment has numerous factors that could impact the pathway; on the other hand, there are many possible accidents

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<sup>186</sup> Shapiro 2006

that could happen within the metabolic system itself.<sup>187</sup> Together these two factors significantly multiply uncertainty. Therefore, it is hardly convincing to eradicate any model of a primary life form by arguing that it cannot evolve to achieve the biological complexity of our own.<sup>188</sup>

The other concern is whether or not a pure metabolic system can evolve without being able to pass down information. Information can only be preserved through certain replications. It is highly likely that a metabolic system without replication cannot evolve because metabolism by itself does not deal with information. People who support metabolism-first emphasize prebiotic evolution or chemical evolution. As early as 1985, Dyson<sup>189</sup> advanced the concept of prebiotic evolution, claiming a metabolic system can evolve before the emergence of genetic replication. What Pross proposed is the same theory. His theory explains how a system of chemical processes could evolve as a side-effect of pursuing a higher level of complexity to acquire new mechanisms. This pursuit can drive not only the prebiotic evolution before genetic materials became stable in life, but also the evolution of concrete life forms. Pross tries to involve the prebiotic evolution in Darwinian evolution by emphasizing the pursuit of complexity as a prebiotic driving

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<sup>187</sup> As we saw earlier in the mechanism of RNA replication, although there is a general tendency that short chains will be preferred in the replications, we cannot predict precisely when and which chain will be replicated, which one is preferred and to what extent. These are internal uncertainties in the system that make it impossible to predict the pathway exactly. We need to be aware that we don't really have the ability to predict something so simple as motions in the physical world. For example, as long as we have three bodies in a motion system, their motions are not predictable any more. In a 2022 book, *The Primacy of Doubt, From Quantum Physics to Climate Change, How the Science of Uncertainty Can Help Us Understand Our Chaotic World*, the author Tim Palmer goes through the most up to date studies in quantum physics, meteorology, etc., to see how limited our power of prediction is in the physical world.

<sup>188</sup> Achieving the bio-complexity of human beings is not a part of the requirements for life. Even if life on Earth had never evolved beyond the complexity of insects, this does not compromise their authenticity as being alive.

<sup>189</sup> Dyson 1999

force.<sup>190</sup> After Pross's 2011 book, Smith and Morowitz published a book in 2016 to further support this idea. They suggest that the essential character of living systems is that they maintain a state of low entropy by continuously exchanging energy and matter with their surroundings. To understand the energy flow is to understand life itself and the metabolic process is the method for exchanging energy by capturing, storing and utilizing energy from the environment. While Pross uses RNA replication as the model of autocatalytic systems, Smith and Morowitz's model of autocatalytic system is a self-sustaining metabolic network. They suggest that everything started with autocatalytic cycles where the system produces the same molecules they consume. With this energy flow, the metabolic system starts to be able to capture and utilize energy from its environment: some primitive metabolic pathways emerge.<sup>191</sup> They suggest the autocatalytic circle was formed with the help of geochemical processes. Those processes also helped to drive the energy through the primitive metabolic networks. Metabolism started as a stage of chemical evolution in the prebiotic world, yet the evolution of the metabolic networks led the system into the biological world. Smith and Morowitz do not try to argue for a dividing point between living and nonliving things.

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<sup>190</sup> Although Pross (2012) did not pick a side in this controversy between metabolism-first and replication-first, he spent a lot of time digging into the mechanism of RNA replication which is normally considered as the basis for the replication-first stance. Yet in this 2011 paper, he clearly pointed out that metabolism can exist and evolve before being able to replicate. He only sees continuity in the whole development procedure. For Pross, metabolism can happen without replication (Pross 2011), while replication can happen without metabolism (Pross 2012). Neither of them marks the beginning of life. If we really need a beginning of life, we need to be aware that the metabolism and replication we have today are mutually dependent on each other. What Pross means is that, in certain laboratory settings, scientists observed possible replication/metabolism without each other. Although there are still many unsettled discussions about this experiment, it is possible to have replication without metabolism and metabolism without replication. Pross, following an ahistorical method, only needs this possibility to support his point, because he only focuses on life itself without consideration of what really happened at the beginning of life.

<sup>191</sup> We do not need to worry about how far this system can be advanced or whether the system will be able to evolve. We do not need to search for this evidence here—the reason is addressed earlier in this section (Smith and Morowitz 2016).

Following Pross's strategy, they look for some mechanism that can make the whole process a unity. By doing this, they do not pick a side in the metabolism-first v.s. replication-first controversy. If the continuity is well established, one can cut the sections and name them in whatever way one wishes: the differences are merely artificial.

#### 4.4 Autopoietic systems

The autopoietic system, as a popular model of a minimal form of life, can save us from becoming bogged down by this continuity issue. The concept of Autopoiesis was first formulated in the 1970s by two Chilean biologists, Humberto Maturana and Francisco Varela, to capture the essence of life as an emergent and self-sustaining phenomenon. The term “autopoiesis” is derived from the Greek Words “auto” (self) and “poiesis” (creation or production). This term is used to capture the self-sustaining and self-producing characteristics of systems. “Self-sustaining” in this context refers to the capacity to continually reproduce and maintain the functions of the very components that constitute them. “Self-producing” suggests that the system can produce things required to maintain the unity of the system. One such system, in discussions of autopoietic systems in life,<sup>192</sup> is a network of chemical reactions, which are perpetually engaged in balancing creation and destruction of the network’s constituents.

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<sup>192</sup> The same system can be actualized in other fields. For example, cultural norms and values can be thought of as autopoietic because they maintain and reproduce themselves through the ongoing practices in a society. We will focus on such a system being actualized by chemical reactions. However the study of the autopoietic system in other fields, especially in social studies, i.e., social organization, do re-develop this question: what is life? If life is defined by its autopoietic organization, then can other social organizations with the system be qualified as alive?

In an important paper of 1974,<sup>193</sup> Varela, Maturana and Uribe claimed that there exists a particular common organization that we can implicitly recognize, which makes living systems different from non-living things, namely, being autopoietically organized. Such systems have the ability to continuously produce and maintain themselves through their internal processes within the system. They are open to the environment only in the sense that they can exchange energy and selective matter with the external world in order to maintain the process inside the systems. This interaction is called structural coupling in the sense that the autopoietic system and the environment mutually influence each other's states and dynamics. The structural coupling is clear when we consider the mutual influences between living organisms and their environments. Cyanobacteria, one of the earliest known life forms, have played a crucial role in shaping Earth's atmosphere. They are photosynthetic bacteria. One of the byproducts of their metabolic process is oxygen.<sup>194</sup> The proliferation of cyanobacteria contributed to a significant rise in atmospheric oxygen levels about 2.4 billion years ago. This increase in oxygen concentration transformed Earth's atmosphere to enable the evolution of more complex aerobic life forms which rely on oxygen for respiration.<sup>195</sup> Conversely, as photosynthetic bacteria, the behavior of cyanobacteria is directly influenced by the light availability and temperature in their environment. Depending on light energy to maintain their metabolism, their growth rates are affected by the intensity and quality of light they receive.<sup>196</sup> Hibernation of animals is another example of how the

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<sup>193</sup> Varela et al. 1974

<sup>194</sup> Falkowski 2006

<sup>195</sup> Holland 2006

<sup>196</sup> Kirk 2011

environment shapes the behavior of living beings: some animals adjust the rate of their metabolism to accommodate the changes in their environment. Autopoietic systems must be structurally coupled with their environment.

Varela and Maturana make two important claims in this paper.<sup>197</sup> On the one hand, they believe contemporary biology studies of molecular, genetic and evolutionary phenomena overemphasize isolated components of living things. However, “the properties of a unity cannot be accounted for only through accounting for the properties of its components”.<sup>198</sup> They believe that the autopoiesis system they propose is what is shared by all living things. On the other hand, they assert that reproduction and evolution are not “constitutive features of the living organization --they are only secondary to the establishment of this unitary organization.<sup>199</sup> They agree that reproduction is essential for evolution, and the adaptiveness of life. Yet they claim that we need to establish a unity which is to be reproduced before reproduction comes into the picture. Therefore, as we work on defining this unity, reproduction is not a primary constitutive aspect of the unity.

Instead of formulating a comprehensive system of theory of life, the approach they take is to pin down a minimal form of life. According to Varela, Maturana and Uribe, this model is significant in two respects: First, “it permits the observation of the autopoietic organization at work in a system simpler than any known living system, as well as its spontaneous generation from components. Second, it may permit the

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<sup>197</sup> Varela et al. 1974

<sup>198</sup> Varela et al. 1974, page 187

<sup>199</sup> Varela et al. 1974, page 187

development of formal tools for the analysis and synthesis of autopoietic systems".<sup>200</sup>

Like Pross's theory mentioned, the theory of the autopoietic system does not consider the origin of life in the sense of how and why inorganic reactions become autopoietic systems. It focuses instead on how living systems work and how they interact with other systems, such as environments and cognition. Although they do not care about how a system changes from non-living to living, they do provide us with an understanding of how the cognitive system is embedded in the autopoietic system in the sense that cognitive processes are an inherent aspect in a living system.<sup>201</sup> If the autopoietic system is an appropriate model of the minimal form of life, and, at the same time, can be applied to systems other than individual living beings, then we have a solid ground to evaluate to what extent a geosystem can be considered to be alive. In this paper, Maturana and Varela give a clear statement for what a living system is:

"the organization of the living system is identified as a circular network of production of components which (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network."

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<sup>200</sup> Varela et al. 1974, page 189

<sup>201</sup> Later, there are scholars who criticize this definition of life by suggesting the possibility of applying the autopoietic system to social and cognitive domains. See for example, Luhmann, N. (1990). *Essays on self-reference*. Columbia University Press. von Glasersfeld, E. (1991). *Knowing without metaphysics: Aspects of the radical constructivist position*. In F. Steier (Ed.), *Research and reflexivity* (pp. 12-29). Sage Publications.

Autopoiesis refers to the self-producing and self-maintaining nature of the living system. It is in contrast to allopoiesis. The latter consists in a system that produces something different from itself. An assembly line in a factory is an example of this — whatever is produced on this line is different from itself.<sup>202</sup> The products will not contribute to the function of this assembly line in the future. What if this line produces a certain component that can be used, and will be used in the assembly line, say a screw? To catch the essence of being alive, autopoiesis must also signify that the system is producing things that the functioning of the system constantly depends on. If we review the behaviors of a living system, this relates to the fact that once a living system stops producing, it cannot be restarted, even if we have all the required materials available again. Therefore, what is being produced, whether or not it is different from the system, is not sufficient to determine if a system is alive. What matters is the particular relation between components of the system: the constant interdependence. The contrast between autopoiesis and allopoiesis only makes clear that all of the components in the autopoietic system are constantly being produced/ fixed by the system itself.

According to Evan Thompson,<sup>203</sup> one important characteristic of an autopoietic system is having organizational closure. This term refers to “the self-referential (circular and recursive) network of relations that defines the system as a unity, and operational closure to the re-entrant and recurrent dynamics of such a system”<sup>204</sup>. According to Thompson, the difference between organizational closure and operational closure is

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<sup>202</sup> Even in the case that a robot assembles other robots identical to itself, those products are still not the self – they only process the same form, but still different individuals.

<sup>203</sup> Thompson 2007

<sup>204</sup> Thompson 2007, page 45

important in understanding what life is in an autopoietic sense; yet Varela<sup>205</sup> tends to use these two terms interchangeably. It is common to understand this closure as characterized by a boundary (a membrane) that can separate the interior of a living being from the exterior world. The boundary is a membrane in the sense that it permits selective exchanges of matter and energy. Having such a boundary, the chemical system inside the boundary exhibits autonomy by maintaining its organization using energy and materials from the world outside the boundary. The autonomous system inside the boundary is able to adjust its own system to adapt to any changes in the world outside the boundary. This ability of adjusting is part of the self-sustaining system. An autonomous system is always structurally coupled to its environments; Structural coupling points to the recurrent interactions between systems that can lead to structural congruence between them.<sup>206</sup> In the case of living beings most can reduce the burning of energy or even stop it when the environment cannot provide them with sufficient resources to maintain their normal energy burning rate. A seed is a more extreme example: a seed will show no sign of life until life function is triggered by an appropriate environment. Thompson argues that this closure should be used in its algebraic sense: “an operation  $K$  exhibits closure in a domain  $D$  if every result of its operation yields results within  $D$ ”.<sup>207</sup> This suggests that everything being produced by the system stays in the system, and will participate in the process of production to produce something

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<sup>205</sup> Varela 1979

<sup>206</sup> Maturana and Varela 1987, page 75

<sup>207</sup> Thompson 2007, page 448 Footnote 4

belonging to the system again. This makes this closure different from a materially closed system, i.e, a system that is closed to interactions with what lies beyond it.

The concept of autopoiesis emphasizes a system's ability to maintain and reproduce its own organization through continuous self-production. Self-production puts emphasis on a system's ability to generate its own components and maintain its boundary, which are the features of metabolic processes. The autopoietic concept of life suggests that metabolism plays an essential role in primary life forms as it is an individualized functional system maintaining its function and its boundary by exchanging materials with the environment. Replication does not play a central role in this process. However, autopoietic understanding of life does not conclusively solve the discussion of whether metabolism or replication comes first, because, like Pross's theory, it is an ahistorical study of life which searches for an operational and organizational principle of life. It can only tell us which of the two, replication or metabolism, emerges from the inorganic world first. Instead, it suggests metabolism is more essential for life forms now. To account for organisms' ability to travel a developmental pathway, an autopoietic system is not enough since replication is essential for any type of development. Autopoietic theory, however, is sufficient to bridge the gap between organic and inorganic worlds.

#### 4.5 Conclusion

Although there are still controversies about how life comes to be, which theory is the best model of life in general and whether or not there is one theory of life for all life forms in general, the developments in science since Hegel's time follow the basic

understanding of life that Hegel proposed. Living organisms can be understood through the inorganic constituents they have and they always follow the universal laws in physics and chemistry just as inorganic beings do. Scientists have been trying to find out the most efficient model of life which can catch the minimal requirements of life. Although there is not one generally agreed model of life, it is clear that Hegel's theory, regardless of his ignorance of advanced knowledge of chemistry, genetics and evolution, lays the fundamental structure of these advanced studies.

One question this dissertation attempts to deal with is whether or not having a list of the criteria of life is an appropriate way to look for the concept of life. As contemporary science allows us to study life on a more and more microscopic scale, it seems reasonable to believe that organic and inorganic beings are on a continuous spectrum. Finding a dividing-line between the two by providing certain criteria is not the answer. On the one hand, as discussed above, when we focus on a very detailed level, some characteristics may not be clearly distinguishable from each other – metabolism and replication are not two clearly separable characters of a system. On the other hand, because of this characteristic of continuity of living and non-living, the way we distinguish living and non-living is often subject to the context in which we have the discussion. For example, in the discussion of abortion, neither replication nor metabolism is the defining characteristic of being alive. The reason why the Hegelian study of life is more complete is that his discussion is not limited to any particular content. It cannot pin down how much replication and metabolism weigh differently in organic beings in a general sense, yet it makes it clear that following the general theories in the natural world, chemical systems will be able to develop new

characteristics beyond the scope of physical laws, and allow us to see how they are different. Hegel does not focus on life itself trying to come up with one list to compete with others. Instead he takes the emergence of organic beings from inorganic beings as a part of a developmental path.

## CHAPTER FIVE

### GEOLOGICAL PROCESSES

#### 5.1. Hegel's Idea of the Geological Processes

Hegel suggests that chemical processes are essential enabling conditions for life to emerge but are not sufficient for life to arise and sustain itself. Hegel sees the necessity to conceive of a sufficiently supportive and stable environment in addition to chemical processes before we can speak about the emergence of life proper. He introduces what he calls the “geological organism” as the necessary precondition of life. It comprises the compatible environment essential for the survival of living organisms. Before our current biosphere, there was a prebiotic environment on the Earth in which life proper did not exist. Although it was a lifeless world, the existence of such a world is one of the sufficient conditions for life to emerge and sustain itself. Hegel suggests that this lifeless world must acquire certain *quasi* organic properties, such as a certain level of self-regulation, to be the womb and host for life. Because of the possession of those *quasi* organic properties, Hegel prefaces his determination of living organisms with what he calls the “geological organism”.

Hegel believes that a simple and random collection of separate mechanical and chemical reactions is not sufficient for life to sustain itself, although such a collection might, accidentally, enable living systems to emerge momentarily without being able to sustain themselves. They are merely “punctiform, and transient forms of life” (Hegel and

Miller 2004, page 407).<sup>208</sup> What are the characteristics of the geological organism that make this inanimate organism of the earth “a crystal of life”?<sup>209</sup> Hegel suggests that by being the subject of the geological process, the Earth is “fructified into vitality as in itself the totality of life” (Hegel and Miller 2004, page 294). For Hegel, the pre-life Earth must possess a kind of vitality to be able to host life. The questions we need to ask are: What exactly is this vitality? What gives it unity? How is it different from life *per se*? How is it necessary for life to emerge and subsist?

Hegel begins his discussion with an acknowledgment of how the Earth has its history of formation outside itself. This is a key difference between organic beings and inorganic beings. The formation of the Earth is neither powered by itself, nor necessitated by itself. The formation here includes both the creation of Earth and the process which brings the Earth to its current geological state. “The process of formation... is not in the earth itself, simply because this is not a living subject” (Hegel and Miller 2004, page 279). The physical existence of the Earth, including its shape and position relative to other celestial bodies, resulted from astrophysical developments; the geological conditions of the Earth, such as its atmosphere and geological structures depend upon its relation to the Sun and other celestial bodies. None of these terrestrial features are dictated by the form of the Earth itself. Hegel suggests, “[the Earth] endures, it does not produce itself” (Hegel and Miller 2004, page 279). This is already, in Hegel’s opinion, in spite of similarities, sufficient to claim an essential difference

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<sup>208</sup> They are restricted to “punctiform and transient forms of life” because they do not develop internally into a specifically articulated organism, or reproduce themselves *ex ovo*” (Hegel and Miller 2004, page 294). From here, Hegel makes it clear that life proper must have a necessary reproductive ability to reach its stable and complete form. This could be one of the definitive criteria which disqualify the geological organism as life proper.

<sup>209</sup> Hegel and Miller 2004, page 293

between the Earth and living beings. In order to be the host of life, the Earth had to undergo long periods of geological and atmospheric change to become the way it is now. The processes Hegel discusses under the title “History of The Earth”<sup>210</sup> might not be completely accurate. Even now, our knowledge about the pre-biotic earth is limited; yet we understand that there was a long period of geological history during which the Earth was a hostile place for the life forms we are familiar with. The *quasi* organic character of the Earth is similar to what Hegel sees fungi as already having in the prebiotic Earth. Hegel suggests “fungi do not ... grow but suddenly shoot forth as crystals do” (Hegel and Miller 2004, page 299). The Earth is an accidental product from astrophysical developments and was shaped in its relation with other celestial bodies. These processes were all the result of inorganic interactions between materials. Through that history, the Earth acquired *quasi* organic characteristics, a self-regulating mechanism, to maintain its condition.

Hegel’s discussion of the geological organism draws our attention to how it provides necessary conditions for life to arise and be able to develop. In Hegel’s understanding, the prebiotic Earth has three layers of processes making life possible. The first layer is the atmosphere, which involves two processes of its own. One consists in the form of motion of the atmosphere caused by the Earth’s relationship to other celestial bodies. The motion of the atmosphere is mostly driven by solar radiation. Solar radiation leads to temperature differences in the atmosphere. These temperature differences cause atmospheric pressure differences which eventually cause the formation of wind and climate patterns. The Earth’s revolution enhances this effect by

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<sup>210</sup> Hegel and Miller 2004, page 278-285

affecting the heating patterns of the atmosphere. The Earth's rotation also adds a force to the motion of the atmosphere. This motion provides a real possibility for the emergence of living beings. The fact the Earth can maintain an atmosphere and the atmosphere has motion are both determined by the Earth's relation to other celestial bodies. Without the atmosphere, the Earth is subject to lethal solar radiation, and some other hostile extraterrestrial factors. In addition, the motion of the atmosphere is an important mechanism which can stabilize the temperature on Earth, shielding it from external influences.<sup>211</sup> However, Hegel points out that "the meteorological process is not the life-process of the earth" (Hegel and Miller 2004, page 295), because it does not have any organic character in its motion, and it lacks the capacity to foster any forms of life within it. However, the motion of the atmosphere does provide the Earth with a certain level of self-maintaining power which can stabilize its own environment. This is not purely inorganic because it has a purpose to achieve – namely, to maintain a relatively stable environment.

Secondly, there is the movement of the sea and the flow of water on the Earth, which has a higher level of *quasi-vitality* (i.e., *quasi-Lebendigkeit*)<sup>212</sup> for two reasons. First, the flow of water has more interactions with other elements on the Earth. The different varieties of natural water, such as fresh water and sea water, suggest that there are genuine interactions between the water and other elements on Earth. This is

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<sup>211</sup> The details of this mechanism is elaborated earlier in this section in the discussion about the agency level of the geological system.

<sup>212</sup> Hegel and Miller 2004, page 296

in addition to mere movement as Hegel suggest in the motion of the atmosphere.<sup>213</sup>

Second, it involves “a living process which is always on the point of breaking forth into life” (Hegel and Miller 2004, page 296). Being able to bring many elements together, the motion of the sea provides more possible interactions and combinations of different elements. This constant mixture provides a tangible possibility for organic beings to emerge. Yet, the motion of the sea itself is not organic in character – it results from “the changing positions of sun and moon and from the shape of the earth” (Hegel and Miller 2004, page 295). The land has a different kind of *quasi*-vitality from the sea because the latter, according to Hegel, “brings forth mainly animal life, the Earth tends rather to bring forth vegetable life” (Hegel and Miller 2004, page 295). This is not a reliable claim. He suggests that botanical forms of life suddenly shoot forth as crystals do<sup>214</sup> – this is similar to the random organic combinations in the sea. Their parts interact with each other in an organic way – for that Hegel considers them the organs of their unity. However, Hegel’s claim that the sea brings forth animal life and the land botanic life is untrue. This most primary form of life involves no plants or animals. What is important in this section is that Hegel indicates how the motion of the atmosphere, the sea and the land makes possible the emergence of living organisms.

In general, Hegel sees the Earth as an interconnected system in which various geological processes are influencing each other in nature. In this sense, the climate, water cycles and other geological systems form a *quasi* organic unity by mutually

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<sup>213</sup> With contemporary science, we understand that atmospheric motion is also related to the carbon cycle and, henceforth, the rock cycle. But the interactions are still limited and not inherently inevitable. In contrast, the interaction of the sea to other elements on Earth is inevitable and more profound.

<sup>214</sup> Hegel and Miller 2004, page 299

sustaining each other. This lifeless world may exist for many millions of years before organisms happen to form.

In the *Zusatz* of Chapter 341, Hegel points to several geological processes on Earth before life arises which appear life-like. One is that the Earth, as a biosphere, must be sufficiently stable to sustain life. To fulfill this requirement, Earth must have the power to maintain itself in a relatively stable condition – otherwise major terrestrial changes could wipe out life on Earth completely.

One can think of the Earth as a totality that has a self-maintaining purposiveness on a global scale. It might not always have been like that – at the time when Earth came to be, the Earth might not have had such a self-maintaining power. Occasional interactions among different geological processes can accidentally form some mutually dependent relationship. The Earth's interrelated geological processes resemble a functioning organism with parts that are mutually dependent, serving as means and ends to each other. In the case of animals or plants, such organic mutual interdependence is clear: organs depend on each other to fulfill each of their own functions, and each is an indispensable part of the organism. For example, the heart can only fulfill its function if all other organs, e.g. lungs, brain, and so on, function properly. Meanwhile, none of these organs can function if the heart does not pump blood. In the case of the geological system, the analogical “organs” are primarily different meteorological phenomena or climate systems. The hydrological cycle is an example of how the Earth’s interactive system resembles an organic unity. This cycle is the continuous movement of water on, above, and below the surface of the Earth. It is driven by energy absorbed from the sun. Precipitation and evaporation are parts of the

cycle. Solar energy evaporates water from the surface of the Earth to form clouds; clouds produce precipitation in the form of rain, snow or hail. This cycle maintains itself by the interactions between each of its components; each of these components is maintained by being a part of the whole system. For example, if rain, as one type of precipitation, were isolated from the meteorological system, it would have no power to renew itself. Water stored in the clouds would fall to the ground due to the gravitational force, but rain would not reoccur if it were detached from the hydrological cycle.

The hydrological cycle also interacts with other cycles in Earth's pre-biological world which depend entirely on physical and chemical processes. One example is the interaction between the hydrological cycle and the atmospheric cycle. The term "atmospheric cycle" refers to the transfer and movement of matter and energy within Earth's atmosphere. It consists in the large-scale movement of air and the ways in which atmospheric heat, mostly from the sun, is distributed around the Earth. These two cycles are highly interconnected. Here are some of the main ways they influence each other. Water molecules gain enough energy to evaporate from the bodies of water into the atmosphere. The evaporation is driven by solar energy input and atmospheric heat and the evaporation rate depends upon the temperature and humidity of the atmosphere. The evaporation, in return, affects the humidity and temperature of the atmosphere. The temperature, humidity, and pressure changes in the atmosphere also power the condensation and precipitation in the hydrological cycle. When water vapor, transported by wind to cooler layers of the atmosphere, cools down, it condenses to form clouds. When the water droplets grow large enough, they fall back to the ground as precipitation in the form of rain, snow, or hail. It is the atmospheric cycle that carries

the water vapors to different locations and then changes the state of the materials.

These two cycles together are the most significant factors that determine Earth's climate. Water vapor in the atmosphere is one of the most critical greenhouse gasses, playing an important role in determining the global climate.

Other geological activities in the pre-biological world include the rock cycle, carbon cycle and so on. The carbon cycle, before life arrives, involves an interchange of carbon among the Earth's mantle, crust, oceans and atmosphere. Through this cycle, carbon is transformed into several different forms such as carbonic acid or carbonate rocks. When life emerges, this cycle expands to involve carbon living organisms. The rock cycle describes the dynamic transitions among three main rock types: sedimentary, metamorphic and igneous. It is mostly powered by the crustal movement and the heat and pressure on Earth. The carbonation of rocks is a point where these two particular cycles intersect. However, they do not intertwine with each other in a necessary manner. The rock cycle would still exist if it did not meet the carbon cycle at any point. This interrelation is different from that among organisms of living beings. For organs, interacting with certain other organs in a certain way is their identity. Without some interactions, the organ cannot fulfill its function, i.e., it dies.<sup>215</sup> Those inorganic cycles form a unity which allows the Earth to maintain itself through the maintenance of the complementary geological systems that enable the Earth to carry on as a relatively stable whole. This self-maintaining balance may not exist at Earth's beginning, and may

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<sup>215</sup> The carbon cycle and rock cycle are fundamental geological concepts that can be found in most of the geological and Earth Science textbooks. The well-regarded textbook, *Earth: An Introduction to Physical Geology* (Tarbuck et al. 2005) is used here.

not last forever. A planet may have such a self-sustaining power but maintain itself in a condition which is hostile to life.<sup>216</sup>

Moreover, this self-sustaining process is not equivalent to metabolism, growth, or reproduction. Reproduction involves increasing in number. Growth involves increasing in size or maturing in function. Metabolism consists in the assimilation of external materials and their transformation into organs of the living thing. The interactions between the geological and meteorological cycles, in the pre-biological world do not transform any materials into something which is essentially different.<sup>217</sup> Their interactions are merely accidental in that the cycles do not depend on any of the interactions for their own function. Without these interactions, some of the cycles might be changed, yet their existence is uncompromised. For example, the rock cycle, which involves the formation and erosion of rocks, is deeply influenced by other terrestrial processes such as plate tectonics, yet it can operate without any interaction with other cycles, e.g., the carbon cycle or nitrogen cycle. The situation is the same for the hydro-

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<sup>216</sup> Whether or not a life form can sustain itself in an environment is a “matching game”. The range the Earth is able to maintain happens to be tolerable to the life form that emerges on the Earth. Life forms today may not be able to survive an ice age, but many life forms during that period happened to be able to survive it. We think the extreme inclement climate on Mars is impossible for any life on Earth to survive, yet it is possible for a form of life that can prosper in that kind of conditions. This compatibility of the environment and the life form emerging from it is an accidental product whose existence is not necessitated by those conditions. The lack of necessity is the main reason why the geological process is not a proper life form. The Earth happens to be able to maintain an environment for terrestrial life to survive. In a famous hard-science-fiction, which is the genre of science fiction that is based on realistic and accurate science and technology, *The Three-Body Problem*, the author describes a planet with a chaotic climate due to the three suns in their solar system. Trisolarans, creatures on this planet, adapt by dehydrating into a dormant state during extremely inhospitable conditions, and reviving only when a life-friendly climate returns. Most of the life forms on Earth cannot survive on the Trisolarans’ planet. It is hard to say how stable an environment needs to be to host life. Even on a planet on which the climate seems unstable by our human standards, life forms with compatible living strategies can survive. The key for the development of life is for the life form to emerge in an environment that it can cope with.

<sup>217</sup> The formation of rocks in the geological cycle may involve chemical reactions. Metamorphic rocks are formed when existing rocks are subject to high temperature and pressures that cause physical and chemical changes. However, the interaction between the geological cycle and other cycles does not cause chemical reactions in other cycles; and the material changes stay within the geological cycle. The geological cycle affects other cycles with its physical, not chemical properties.

cycle – its function does not depend upon its interaction with other cycles. However, it is possible for this system to receive materials from the outside: an aerolite, such as a meteorite, from outer space could break into these systems and cause significant impact. Facing these impacts, the system may or may not be able to adjust itself to maintain the stability of the environment.<sup>218</sup> However, the system does not depend upon the incoming materials to maintain the movements and interactions in the system.

Another major difference is that proper life forms possess an inherent driving force which drives the living being to actively interact with the external world by extending itself in some way. Given how the sun and other celestial objects are affecting the Earth, such as by providing heat, maintaining the Earth's rotation and spin, and causing tides, there is no doubt that the celestial environment enables the terrestrial environment to maintain a relatively stable geological system. However, these interactions are significantly different from the interaction of organic beings with their environment. Leaves grow towards the sun, and roots reach deeper towards water. If the resources are not nearby, the living being pursues them. In the case of animals, their inner drive can physically move them towards resources they need to survive. The same situation even applies to many primary life forms. There is an active dynamic in the interaction between all organisms and their environment. In biology, this difference is measured by the different levels of agency.<sup>219</sup> Animals exhibit a higher level of agency, compared with plants, in seeking out resources necessary for survival. Compared with

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<sup>218</sup> There is a possibility that the system is incapable of maintaining itself after these unexpected impacts from outer space. Then all current life will be erased from the planet.

<sup>219</sup> “Agency” in biology refers to a system’s capacity to make goal-directed interaction with their environment” (Ball 2023). The goal is its own persistence, maintenance and function.

both plants and animals, the geological system interacts with its external environment in a more passive manner – it does not alter how much sunshine it receives from the outside, and it has no ability to move towards different resources. Flowers can turn to the sun or extend towards the sun, but cannot uproot themselves to move towards it. Although there are certain active responses in this interaction, the geological systems, compared with living beings reaching out towards selective external resources, have a significantly lower level of agency.

The geological system as a whole also contains different cycles that work together to stabilize the climate against irregular perturbations. The Albedo Effect<sup>220</sup> is one example showing this agency of the geological system. The Albedo Effect refers to the capacity of the Earth's surface to reflect solar radiation. Ice and snow have high albedo values in that they reflect most of the solar radiation that reaches the surface. In high-altitude regions, the presence of ice and snow can reduce the amount of solar energy that is absorbed through the surface of the Earth. This is a natural cooling mechanism. When the ice and snow begin to melt, the land or ocean beneath them are exposed to the sun. Those surfaces have lower albedo values. They absorb more solar radiation which leads to further heating and melting. This is a mechanism that can accelerate climate change. In contrast, clouds act as a negative feedback mechanism that can stabilize temperature change. As the temperature increases, more water vapor enters the atmosphere forming more clouds. Thicker clouds reflect more solar radiation which can help cool the Earth's surface. The natural regulatory mechanism

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<sup>220</sup> There are other mechanisms on Earth which work as geological stabilizers. The reason I elaborate on this Albedo Effect is that one of James Lovelock's main arguments is based on one example of the Albedo Effect, the DaisyWorld. Understanding the Albedo Effect will have understood his argument later.

can help the Earth to resist climate change caused by external factors, such as solar activities<sup>221</sup> or human activities.<sup>222</sup> The current global warming is a result of human activities that bring about changes that natural geological stabilization cannot remedy.

Living organisms exhibit individuality. One plant can be distinguished from another, one lion can be recognized from others in its pack. This individuality is exhibited by the enclosed boundary of the living individual, e.g. skin is the boundary for each animal. This boundary is essential for identifying metabolism, growth and reproduction. The concept of metabolism is based on a distinction between an inside and an outside: it is assimilating things from outside the boundary to become what is inside the boundary. Without the distinction between outside and inside, metabolism does not make sense. Growth is normally related to the change of the size of the individual. Without a boundary, we cannot determine the size of a thing, not to mention the change in size. However, growth can also involve morphological changes related to maturation and aging: human beings eventually grow older without becoming larger. However, how can we talk about the level of maturity without having a well defined target to be evaluated?

The necessity of having a boundary is most obvious in reproduction. Reproduction is a process whereby organisms produce others of the same kind. If we do not have the boundary of one, we cannot have more than one. These three processes, metabolism, growth, and reproduction are important factors in the concept of

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<sup>221</sup> The Earth can only stabilize itself in some solar activities, such as Ultraviolet Radiation Variability, Sunspots and so on. When the Sun burns up its fuels to turn into a Red Giant, there is no way the Earth can use its natural stabilizing system to escape from that explosion.

<sup>222</sup> Human activities such as deforestation and the use of fossil fuels.

life. Therefore, when we try to identify the three life-like characteristics of the geological system, we need to determine whether the geological system has an analogous boundary and analogous processes. The material essence of this geological system is a group of physical reactions which acquires a self-sustaining function. Yet how self-sustaining does a group of terrestrial processes need to be in order to be considered as one unity? For example, we generally consider the Earth a self-sustaining system, yet it depends upon the energy input from the sun to maintain itself, because solar energy is the driving power of the water system, which is an essential constituent of the geological system of earth. So should the Earth, or the Earth with the sun, be considered a self-sustaining system? Is the interaction between the Earth and the sun a viable analogy of metabolism? We want to identify self-sustaining systems to define individuals in organic nature. Identifying the boundary of our geological system can be complicated. However, this is not a task Hegel takes on in his inquiry. What he intends to show is that life can only emerge and sustain itself under certain environmental conditions. Before life arrives, separate physical reactions will accidentally and gradually interconnect with each other to form a relatively stable system and to accidentally maintain it against external disturbances. Hegel's aim is not to show that such a system has life, but merely point out that there are necessarily some similarities between such a system and life. He thus does not need to discuss all the characteristics of geological systems. He only needs to show that it is necessary for its physical processes to form a system with certain *quasi* organic characteristics, such as a self-sustaining power, for life to emerge from it and sustain itself.

It is clear that there are mutual effects between the inorganic processes on Earth and they may achieve a kind of self-regulation to a certain extent: the self-regulating totality consists of interdependent components which work cooperatively to allow the whole to which they belong to exist over a certain time. However, there are three characteristics that together can distinguish organic beings from inorganic beings: having a continuous metabolism, organic unity, and reproduction. Winfield (2018) points out that the Earth as a whole does not manifest any of these three.

Metabolism, as one of the defining characteristics of life, relates to inorganic nature outside the living system. This interaction between the living being and its environment includes both energy exchanges and material exchanges. The essence of metabolism is to assimilate inorganic materials from the inorganic environment, transforming them into organic constituents of the organic being; the homeostasis of Earth does not depend upon any materials from outer space.<sup>223</sup> To be a metabolic system, Earth would require some part of itself to function as the inorganic environment to interact with the organic system. As Winfield claims, however, “the development of life can never completely absorb the surrounding inorganic nature into the life process” (Winfield 2018, page 10). In other words, the Earth cannot be considered as an organic unity because it does not have an inorganic environment to metabolize.

Another argument Winfield (2018) makes, concerning whether or not the biosphere is alive, draws upon the definition of an organ and the relationships between organs in a living being. Several particular characteristics make organs of a living being different from parts of a machine. First, an organ only becomes an organ proper when it

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<sup>223</sup> There are some materials that enter our biosphere from outer space, yet they are insignificant for the regular geological process on Earth.

is functioning in the organic system. Its identity consists in continually performing its function in the system. As Winfield (2018) points out, “[t]he organs of a living thing contain the life process within their own functioning” (Winfield 2018, page 12). That is to say, an organ is constantly producing itself by performing its function. Without performing its assigned function in the organic unity, the organ is not an organ. The organs do not take part in a unity; the organs functioning is the unity itself. In comparison, the parts of a biosphere are formed before they take part in the self-regulating biosphere. They do not need to take part in this unity to gain their identity. Moreover, the biosphere is an “external system” for its parts – without specific part (s), the biosphere keeps its identity (it may change from a friendly one to a hostile one, but it is still a biosphere).<sup>224</sup> Another characteristic of organs is that an organ performs its function by causing and being caused by other organs in the same system. By performing their own function, they are producing and being produced by each other. The parts of a biosphere do not consistently produce each other. They do have mutual effects upon one another – that is how they become a joined unity. However, all of them have their complete identity and full function before becoming part of the biosphere. None of them is produced by being part of the biosphere. For example, the rock cycle operate before interacting with other geological cycles, whereas organs of an organic being only gain their identity and the ability to function when they are being a part of a functional system. The formation of the biosphere lies in the past although it is functioning at the current time. Because of this, being a part of the biosphere does not require the parts to function continuously. An ongoing metabolism would require its

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<sup>224</sup> Recall from the previous chapter: this is one of the main reasons why Hegel suggests that the geological system is not life proper.

organs to function continuously, since once they stop, there is no independently existing unity for them to come back to.

The nature of organisms necessitates interactions between living beings and the geological environment, therefore the system must be affected by the emergence of life. The geological system containing living beings is a biosphere. Considering the level of agency<sup>225</sup> of organisms in their interaction with their environment, it is reasonable to expect that the biosphere, facing external changes, will have a higher level of agency than the geological system (with no life in it) does. The reason is that living beings, animals and plants alike, have a higher level of agency in their interactions with their environment – adding them to the system gives the system a higher level of agency all together. When humans arrive in this system, the level of agency is boosted much higher. Our interactions with the environment have repeatedly changed the climate and even the ozone layer. We still have the general biological interaction with the biosphere – assimilating materials for nutrition. Yet our rationality, along with our desire to be stronger, give us the ability to reshape our environment through burning fossil fuels, deforestation, and through the destruction and patching of the ozone layer. In addition, because life is more fragile than stone or water, the system with life in it would have a stronger mutual dependency between certain aspects of the system. For example, a minor change in the composition of our atmosphere can lead to the extinction of numerous species, and a significant loss of biodiversity can impact other geological processes, such as the hydro-cycle. The interdependency is stronger, yet is still not the

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<sup>225</sup> See footnote 215 for the definition of “agency”.

same as the organic relationship between organs of living beings. Having such interaction is not the purpose of the being of each component of the geological system.

Without any doubt, reproduction is an important characteristic of life. Hegel maintains that life that is not produced by reproduction is not life proper.

The general mode of vivification (*Belevung*) displayed by land and sea is *generatio aequivoca*, whereas in the sphere of vitality proper, the existence of an individual presupposes another of another of the same kind (*generatio univoca*). (Hegel and Miller 2004, page 296)

That is to say, things that are produced by other organic organisms through reproduction are considered life proper. Organic organisms that are not produced through reproduction can be considered alive, but not life proper. This claim is countered by how life proper may be infertile. Therefore, the fact that the Earth is unable to produce another biosphere through reproduction does not affect whether or not it is alive. However, the fact that the biosphere maintains its relatively stable status without reproduction suggests that it is not analogous to life proper. Reproduction is important in defining life not because it is a means, but almost the only means, for life to sustain itself and adapt to the ever-changing environment. Reproduction is about how the organism sustains and acquires its living form – the vitality to keep it functioning and the structure which makes the functioning possible. When an organism acquires its living form in a purely inorganic world, the form is purely accidental – nothing can guarantee the emergence of living beings. In contrast, being born through reproduction necessitates that the product will have the same living form as the parents.

## 5.2 The Gaia Hypothesis

The Gaia Hypothesis is a modern attempt to establish an analogy between life and the geo-system and it makes a much bolder claim. Whereas Hegel clearly recognizes that the geological system is not life proper, the Gaia Hypothesis assigns life to the whole biosphere.

The original Gaia Hypothesis was formulated by James Lovelock in the 1970s. It was initially considered a hypothesis because of the lack of evidence that could be tested with our empirical scientific methods. The Gaia Hypothesis is based on the observation that all organisms and their inorganic surroundings on Earth are closely integrated to form a single self-regulating complex system maintaining the conditions for life on the planet. The Gaia Hypothesis suggests that the biosphere and the evolution of life forms contribute to the stability of global temperature, ocean salinity, Surface PH, oxygen in the atmosphere, and other factors of habitability in a preferred homeostasis (Lovelock 1972).

Before proposing the Gaia Hypothesis, Lovelock and his colleague, Giffin, had done significant work on what the atmosphere on Earth would look like if there were no life on the planet.<sup>226</sup> Their original purpose was to use this method to detect life on other planets. Their studies successfully showed that lifeless Earth would have as little atmospheric nitrogen as Mars does, or even none. It is no surprise that the environment and the life in it could have an impact upon each other— it is the stability of the environment, regardless of the massive changes outside it, and the fact that the

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<sup>226</sup> Giffin and Lovelock 1969

stabilized environment can support life in it, that transcend the effect of each individual component of the Earth, e.g., water cycle, atmospheric cycle and so on. In Lovelock's 1974 paper, he claims that

Henceforward the word Gaia will be used to describe the biosphere and all of those parts of the Earth with which it actively interacts to form the hypothetical new entity with properties that could not be predicted from the sum of its parts. (Lovelock and Margulis 1974)

This original description of Gaia does not propose to consider the whole system as an organic unity in the same way as some later versions of the Gaia Theory do. However, this hypothetical unity may have some organic characteristics in so far as some of the properties of the new entity cannot be derived from the sum of the parts.

At the time the Gaia Hypothesis was proposed, it was clear that individual organisms can have an impact upon the environment on Earth; however, there were still not sufficient studies to support the kind of interaction Lovelock proposed. He was well aware of this situation. At the end of his paper, he clarified that the purpose of the paper was to introduce new questions about the Earth. "Proof of Gaia's existence may never approach certainty but further evidence is more likely to come from the study of the contemporary Earth" (Lovelock and Margulis 1974).

Ever since the Gaia hypothesis was launched, it faced many significant challenges. Most of the critiques belong to one of two types: criticism of the

hypothesis for its teleological implications; and criticism from the practical scientific point of view.<sup>227</sup>

#### 1. The challenge of anthropomorphism and teleology.

Some scholars suggest that the Gaia Hypothesis attributes a sort of consciousness or purpose to the Earth, which is incompatible with fundamental principles of science. Taking teleology as a core issue, this challenge has been made from several different angles.

Ford Doolittle, a renowned molecular biologist and evolutionary theorist, claims that Lovelock incorrectly attributes a purposeful intent to the biological and physical processes on Earth.<sup>228</sup> Following a neo-Darwinian point of view, Doolittle holds that evolution operates at the level of the gene, powered by random natural selection. There is no planetary-scale goal for the evolution system. Richard Dawkins is another famous opponent of the Gaia Hypothesis. He also holds a gene-centric view of evolution, yet his concern is that the ability to regulate global systems, such as temperature and atmospheric composition, would require certain advanced skills such as foresight and planning. Unconscious processes cannot possess the foresight required.<sup>229</sup> Apart from these two, there are other challenges questioning the teleological undertone in the Gaia

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<sup>227</sup> The second one includes arguments from many different perspectives. For example: It is impossible to test and verify the hypothesis through empirical evidence and scientific experiments because of the way it is structured, the massive amount of data involved, the issues in interaction with other scientific disciplines, and so on. These all represent different critical approaches, but the core objection concerns how to make the hypothesis scientifically acceptable.

<sup>228</sup> W, Ford Doolittle 1981

<sup>229</sup> Dawkins 2016

Hypothesis.<sup>230</sup> Although Lovelock does not formulate his theory with a presupposition of purposiveness, the apparent goal-directedness of the regulatory processes he presents can seem problematic.

One geological example Lovelock repeatedly discusses is the salinity of the oceans. Throughout known history, the salinity of the oceans has remained at a relatively constant level despite inputs of fresh water from rivers and salt from geological processes.<sup>231</sup> Lovelock suggests that ocean salinity is regulated by marine organisms along with other inorganic processes on Earth. The process of salt deposition works with other abiotic processes on Earth and maintains the salinity at a level suitable for marine life. Without such a stable environment, many current marine life forms could not survive.<sup>232</sup> This appears to attribute the intentionality of an organism to the entire planet, as though the Earth intentionally created and maintained conditions which are suitable for life.

## 2. Challenges from the scientific point of view.

One essential challenge the Gaia Hypothesis faces is how to fit in contemporary science. We have a well-developed and widely accepted methodology in science.

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<sup>230</sup> We do not need to go through all the details of these arguments, because Lovelock and his followers argue against these arguments by proving that the perceived teleology is a misinterpretation of the Gaia Hypothesis. Gaia emerges from the interactions and co-evolution of life and its environment.

<sup>231</sup> Several geological processes can increase the salinity of the ocean. The weathering of rocks is the primary source of salts in the oceans. Rainwater reacts with the minerals in rocks to form solutions of different ions. These solutions then transport the ions to the oceans through the water cycle, i.e., rivers, underground water.

<sup>232</sup> Although current marine life cannot survive in an ocean with an unstable salinity level, some other marine animals, which do not currently exist, may be able to adapt to them. There are examples of animals which adapt to increasingly unstable environments through mutation. The Atlantic killifish is a notable case of rapid evolution in response to polluted environments. Over several decades, the killifish in polluted waters evolved the ability to tolerate concentrations of toxins up to 8,000 times higher than clean water populations. Meanwhile, most other species failed to survive this change in the environment (Reid et al. 2016).

Although the inductive testing system in science can only prove the invalidity of a theory, scientists still commonly use it to evaluate new theories. To be an eligibility test subject, the theory must be able to produce testable predictions.<sup>233</sup>

A. There have been plenty of examples of how living beings are able to adapt to the changes in their environment and modify the environment for their own benefit. However, they are not in themselves evidence in support of the Gaia Hypothesis. The subject of the hypothesis is the entire Earth. When the Gaia Hypothesis was first proposed, it was a problem for the hypothesis as to what type of prediction it could give, and how it could be tested. The hypothesis was first presented in a rather descriptive manner – as no more than a pattern Lovelock and his colleagues noticed in the Earth's long geological history. There is here nothing to support any claim for the necessity of the Earth to support life. Considering how short the period of the emergence of life is compared with the Earth's history, it is tempting to assume that life's appearance on Earth was merely a coincidence – much like a single ant crawling across Amy desk at this very moment. We cannot infer from the presence of this ant on my desk that the desk is particularly suitable for an ant crawling, nor that all ants must crawl on such objects. Likewise, Lovelock's initial observation is not sufficient to establish a necessary correlation between "being alive" and "being stable". Therefore, it can hardly support any concrete predictions. The Gaia Hypothesis does require a lot more supporting evidence than our limited observations of the interaction between the Earth and life on Earth to establish a particular relationship, especially a seemingly non-teleological one.

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<sup>233</sup> Although being able to make correct predictions is not sufficient to prove the validity of the theory, contemporary scientists still tend to use this as a basic tool to evaluate new theories. A theory that can make correct predictions may still face other challenges and tests, yet a theory that makes wrong predictions will be eliminated at this stage.

The only concrete prediction it could support is that over a long period of time, the Earth will be able to keep a relatively stable environment, regardless of any possible changes in the environment, sufficient for life on Earth to thrive by the regulation of the work and interactions of cycles – both organic and inorganic ones. Yet this is no more than a speculation: it still lacks falsifiability if we want to test it scientifically. The content of the hypothesis makes it hard to make any specific predictions.

B. The scale of the Earth makes it almost impossible to test the predictions, even if the Gaia hypothesis can make any. The scale is so large and involves so many different disciplines that it is almost impossible for us to evaluate.<sup>234</sup> Therefore, even if Lovelock were able to make some structurally testable predictions, it may still be practically impossible to test them.

C. Lovelock articulated possible mutual influences between the Earth and the living beings on it; he provides no details as to how these interactions occur. To satisfy scientists trained in contemporary scientific methodology, Lovelock has to be able to describe the mechanism of these interactions as fully as, for example, how scientists explain chemical reactions with molecular interactions. Since Lovelock was the first person to propose this comprehensive view, there was not yet any scientific study dealing with such a complex system, not to mention any methodology for such studies. As a result, Lovelock provides no causal explanation for his proposal.

Proponents of the Gaia Hypothesis have further developed the hypothesis through the years in consideration of these challenges. Their efforts fall into three

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<sup>234</sup> This situation is somewhat different now. Lovelock and his proponents in science have been developing methods and computer models to study and simulate the complicated system. Those proofs are still controversial, but the methodology seems promising at the current stage.

categories: 1) proposing the Daisyworld model to demonstrate the core mechanism for the Theory; 2) building upon the Daisyworld Model to show how this system is essentially non-teleological, regardless of how teleological it appears to be; and 3) looking for more scientific support, and using the hypothesis to make testable predictions. Along with these studies, they also work on promoting the cooperation between different disciplines to decode the complex system of Gaia. With all these developments, Lovelock started to use the term Gaia Theory instead of Hypothesis to refer to the more comprehensive and better structured system they put forward.

Facing the challenge of being overly teleological, Lovelock claims that “[i]n no way is this Gaia Theory a contradiction of Darwin’s great vision. It is an extension to it to include the largest living organism in the Solar System, the Earth itself” (Lovelock 1986, page 25). Those who criticized the hypothesis for being teleological misunderstood the core idea of it – the self-regulation achieved through the individual non-teleological actions of living beings and all the cycles on Earth. To back up this claim, Lovelock suggests that the mechanism to achieve such a self-regulation on a global scale without implying any purposiveness can be demonstrated by a Daisyworld model.<sup>235</sup> Lovelock and Watson, in their 1983 papers, describe a model of an imaginary planet with a very simple biosphere<sup>236</sup> with the clarification that they do not attempt to model Earth, but only create a fictional world with all the properties they think are important for the

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<sup>235</sup> Lovelock did publish other papers to support the Gaia Hypothesis before proposing the Daisyworld model in 1983. However, those discussions made efforts to describe scientific facts in a way that can support the Gaia Hypothesis. Since these efforts mostly focus on one cycle, or one part, of the earth, those discussions are not a satisfying reply to the teleology concern. The Daisyworld model is the big breakthrough in the field as it is a response to the teleological charge – which is the strongest challenge the hypothesis faces.

<sup>236</sup> Watson and Lovelock 1983

Earth.<sup>237</sup> There is only one variable environmental factor on this hypothetical planet, temperature. There is no geocycle on this planet – the temperature is only affected by the amount of sunshine reflected from the planet. On this simplified imaginary planet, the only living things are two species of daisies with different reflection rates. There are white daisies which reflect light to make the planet cooler and black daisies which absorb sunlight to make the planet warmer. The growth and proliferation of the daisies exclusively depend on the temperatures, which should ideally be between 20-40°C. The white daisies flourish in warmer temperatures and the black in cooler temperatures. When the temperature falls out of this range, daisies would start dying, making the planet return to its lifeless state. The energy balance is only related to the insulation, surface temperature, and the planetary albedo, which is a measure of how much sunlight is reflected by a certain surface. In the DaisyWorld Model, the white daisies have a high albedo – most of the sunlight hitting white daisies will be reflected back. Therefore, white daisies can cool the area around them; whereas black daisies, as they absorb most of the sunlight that hits them, heat up the area around them. Because of this difference in the white and black daisies, the albedo of a given area is directly related to how the soil is covered by black or white daisies. The number of each kind of daisy will automatically be modified according to the change of the environment, i.e., temperature. As this planet orbits the sun, the heat it receives slowly increases. The increase of temperature makes the white daisies proliferate. With no foresight involved, the surface of the Earth, with an increased proportion of area covered by the white daisies, would reflect more sunshine. As a result, the temperature of the planet will be

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<sup>237</sup> Watson and Lovelock 1983

steady enough for the daisies to thrive. The opposite situation would happen if there were an opposite change in the insulation: the decrease of the temperature would make the black daisies proliferate on the planet. With no foresight, this automatically makes the Earth absorb more solar energy. The temperature of the Earth will increase accordingly. Lovelock and his colleagues believe that such a system can demonstrate how to achieve the kind of auto-regulation described in the Gaia Hypothesis without involving any trace of teleology.

The core of the Daisyworld hypothesis is that a homeostatic state is achieved without foresight for this imaginary planet as a whole. Each kind of daisy behaves in a way according to its own biological characteristics in response to the changes happening in its environment. The stability of the environment on Earth, as being suitable for life to survive, is an obvious fact that we can learn from the history of life on our planet, and it is not controversial that there are mutual effects between organisms and the inorganic environment on Earth guaranteed by the universal laws of physics and chemistry and by the fact that living beings have to interact with inorganic material to survive. People might ask how this proposed organic unity can emerge without an intellectual designer. The self-regulation and homeostatic aspects of the planet are actualized through a dynamic feedback-loop; and this loop is created, by accident, on planets where all the enabling conditions already exist. It requires nothing to necessitate the success of the feedback-loop – it is possible that a particular feedback system is unable to secure the survivability of its biotic component. In this situation, the planet will return to its lifeless state. This may help to remove the confusion as to whether or not this hypothesis is teleological. There is nothing in the system to design and adjust the

feedback-loop to ensure survivability. Considering how short the history of life on Earth is compared with the history of Earth itself, it is likely that our current feedback system is the one success after millions of failures. It is not necessary for a planet with life to evolve to have such a dynamic feedback-loop to ensure the planet is stable with a life-friendly environment.<sup>238</sup> For example, a planet with only white daisies may not be able to increase the temperature efficiently enough when the temperature drops significantly. Meanwhile, there is no guarantee that a planet with an efficient feedback-loop<sup>239</sup> can maintain the life-friendly environment forever—dramatic changes in its environment may destroy the feedback-loop<sup>240</sup> and sterilize the planet.

To summarize, there are three main lessons from the Daisyworld hypothesis: 1) The mutual effects between the biosphere and the inorganic cycles on Earth are necessary due to basic laws of physics and chemistry; 2) Life can become stable by accidentally forming a dynamic feedback-loop that happens to keep a life-friendly environment on Earth. 3) The continuous existence of the feedback-loop is not guaranteed – it can break down due to internal failure or extreme external impacts. Accordingly, it becomes clear that the Gaia Hypothesis does not require intellectual foresight. If we walk on a desolated savannah and see a fridge, we would conclude that there exists an intellectual maker, or makers, for this product. That is the picture people like Doolittle and Dawkins have in mind. However, the structure Lovelock proposes is

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<sup>238</sup> The term “life-friendly environment” in this discussion does not mean an amiable living condition for the majority of living forms to enjoy— it means the environment is not too hostile for all living beings to survive. This situation is, in other words, friendly enough for the biosphere to continue on the planet.

<sup>239</sup> An efficient feedback-loop can successfully maintain a friendly environment for living beings on that planet.

<sup>240</sup> For example, a collision of small, or large, celestial bodies from outer space could potentially completely destroy a biosystem on a planet.

more like the situation when we recognize, say, a dog shape in a cloud. The cloud is formed and stays up in the sky because of the physical laws. No pre-planning is needed to create it or to keep it high up. Wind blows and pushes the cloud following physical laws. The clouds are constantly moved and reshaped as a response to their environment, i.e., the wind flow and temperature. We may recognize a perfect dog shape in a cloud – the shape is so vivid that it is as if it had been designed purposefully. However, there is nothing teleological about this accident. The cloud-dog will disappear as the wind keeps moving. In the Gaia Hypothesis, the shape we recognize, as we recognize the dog shape in the cloud, is the self-regulating dynamics. We recognize that the feedback-loop, which is the result of purely physical and chemical processes, can maintain a life-friendly environment on Earth. Having this life-friendly environment happens to be one of the enabling conditions for the feedback-loop to happen because the biotic world is one component of this feedback-loop.<sup>241</sup>

Understanding the mechanism in this much detail makes it clear that the Gaia hypothesis is consistent with the Darwinian Theory of evolution. Assuming there are many other kinds of daisies, with different traits, living on this imaginary planet, each contributes to their overall impact upon the temperature of the planet. Those who can adapt to the resulting environment will survive and evolve. *Nothing* teleological is required to make the process happen. It may be confusing if one neglects the fact that

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<sup>241</sup> For people like Doolittle and Dawkins, who criticize the Gaia Hypothesis for adding purposiveness to a non-teleological world because of its self-regulation function, it is necessary to reevaluate their understanding of the emergence of life. Although the Gaia Hypothesis is dealing with a complex system on a massive scale, the complexity of the system should be similar to the complexity of one living organism. That is to say, before questioning how the daisies can stabilize the temperature of the world for their own survivability, they should ask, in a world deprived of purposiveness, how the daisies, with more complex self-regulating systems, come to be. If they believe the emergence of a self-regulating system must presuppose the existence of purposiveness, they must solve the same problem with the emergence of life first. If they can accept the emergence of life as being non-teleological, they should have the same understanding for the emergence of the Gaia system.

this non-teleological natural selection also happens on the planetary level – one might ask how it is possible that homeostasis happens to be the condition which is friendly to the biosphere on the planet. Nothing dictated or planned this – planets whose state of dynamic equilibrium is not friendly to their biosphere will lose that biosphere and become lifeless again. Although these changes are not secured through reproduction, this is not exactly the same process as Darwinian evolution, the Gaia Hypothesis and Darwinian evolution agree with each other on the non-teleological development.<sup>242</sup> Although Lovelock and his proponents did not provide many detailed arguments related to his Daisyworld model, the above discussions make clear that the Gaia Hypothesis can stand without implying any foresight or purposiveness.

Ever since the 1970s when the Gaia Hypothesis was first proposed, there have been many developments in scientific content and methodology which could be related to the Gaia Hypothesis. For example, Lynn Margulis, a renowned evolutionary biologist, uses many biological studies to support the Gaia Hypothesis.<sup>243</sup> With the development of computer science, scientists can make simulations of different situations in the Daisyworld to confirm that the self-regulation of the daisies can emerge from a physically realistic feedback system between the plants and their environment with no

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<sup>242</sup> It is not literally a selection. Some last, others do not. Nothing teleological planned it, they just happened as a result of many physical and chemical interactions.

<sup>243</sup> Lovelock and Margulis 1974

need for any planning, neither from the outside nor the plants themselves.<sup>244</sup> Yet a significant number of studies in science and methodology are necessary to determine if computer simulations are reliable and sufficient evidence in the study of The Gaia Hypothesis. However, there is no agreement about what type of cases are eligible to support the Gaia Hypothesis and when they are sufficient to legitimize it.

### 5.3 Conclusion

The proponents of the Gaia Theory have made many efforts to substantiate their claim. Scientific advancements have confirmed many deep interdependence between living beings and their environments and how they maintain their stability as a whole. However, no matter how much something appears to be alive, such as an advanced robot, an organism's way of functioning must necessarily be dictated by what it is, and be constituted by organs, which are essentially different from parts of inorganic beings. Indeed, the biosphere's spontaneous reactions to the external environment exhibit certain particular characteristics that are exclusively possessed by living beings. However, this is just like claiming a plastic bag to be alive by observing how it "interacts" with the wind that blows it around. Flying about in such a manner is not how plastic bags exist, and not what plastic bags are. Such motion is produced in that it is outside the plastic bag itself: the bag itself is not constantly produced by the way it moves. The

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<sup>244</sup> Here are two online stimulators for people to try different possible scenarios in the Daisyworld. <https://gingerbooth.com/html5/daisy/help/index.html>, <https://daisyworld.yale-nus.edu.sg/> The reliability of the Daisyworld model has increased as more varieties of model have been tested on these open websites. Andrew J. Wood published a paper in 2008 to review all the extensions and critiques of Daisyworld since its inception. He concludes that "The existence of detailed analytic solutions backed by comprehensive modeling work has now led to a concrete body of scientific research" (Wood et al. 2008, page 21). However, he also admits that "to truly examine the plausibility of global regulation by the biota" (Wood et al. 2008, page 21), the current model is overly simplified.

proponents of the Gaia Theory seem to cling to the special features Hegel notices in the environment when he sets up the full enabling stage for life and try to prove this with scientific research.

Hegel's discussion of the geological organism, although focused on the role the prebiotic world plays in the emergence of life, demonstrates acute awareness of the similarities between the biosphere and living beings. From the way organic beings relate to their environment, Hegel deduces that the world in which life can emerge and sustain itself must have some organic characteristics beyond being a purely physical world – such as being able to maintain a relatively stable condition. This is the very character upon which the proponents of the Gaia Theory developed their theory. Although Hegel was not equipped with advanced scientific studies which are used to support the Gaia Theory, he grasps the core of what they deal with – which is the ability to maintain a stable status through interdependent relationships within the whole and interaction with external environments. However, the Gaia proponents ignore the reasons why Hegel suggests that the system of geological processes is not life proper regardless of the fact that it has certain life-like properties. Considering the extremely long history of the Earth, ignoring its “coming to be” in the study of the biosphere seems reasonable to the proponents of the Gaia Theory. However, no matter how much supporting evidence they can find in some aspects of the biosphere and in *certain* periods in its history, they cannot *evade* the *disanalogies* Hegel finds: that the formative power of the biosphere *lies* in the inorganic world and the biosphere did not acquire its form from other individuals of the same species. The Gaia Theory stems from a scientific perspective – the theory is empirical and descriptive of our planet. Hegel, by contrast, develops a

philosophy of nature which provides a concept of life that can hold true for any possible planet – our Earth and beyond.

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