Thermodynamics, the Tricarboxylic Acid Cycle, and the Apeiron

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What is life, and what makes it? Where does it come from? Where does everything go to? These questions bridge not only subjects such as chemistry, physics and biology, but subjects such as philosophy as well. In the early days of philosophy, philosophers strived to answer this question by trying to understand what the most basic unit of life is. That is, what is it that makes everything else up? They felt, as do most scientists now, that only by understanding this, could we understand the nature of the world, and how we fit into it. Different disciplines of science have come up with different answers to this based off of their own focus, varying from the concept of energy itself, to various cycles within all types of cells. This question has not been left alone to modern science however, with thoughts and opinions on the subject being recorded on a semi-regular basis since ancient times. The most notable of these thoughts from ancient Greece are thought experiments done by Anaximander of Miletus. Anaximander arrived at the conclusion that all things were made of, or were part of, the "*apeiron*". This essay aims to address how modern understandings of the world and what makes it, in physical terms as well as biological, would agree with the concept of the *apeiron* as we can best determine Anaximander himself described it. This will be done by first determining how the *apeiron* was defined, and then looking at examples of this in biology. It will then explore how the subject of physics would view the *apeiron*.

Much of what we have now in terms of lasting philosophical writings from Anaximander comes from him being quoted by later philosophers. This resulted in many of his words being filtered through others and their purpose for writing. Thus, we cannot take any of the quotes literally as they could have very easily been altered. When trying to apply his philosophy to modern science, that does add something of a hindrance, as a scientific frame of thought relies heavily on prevention of interpretation of information without factual support. However, because there are multiple sources that quote Anaximander, we are able to compare different records of Anaximander's writings and glean from them what we may. This allows us to hopefully arrive at the most probable reasoning for what he meant when discussing the *apeiron*. We can then compare this to modern science to have a best-case discussion. Simplicius, a philosopher in the late 5th century, mentions Anaximander many times in his own writings and has quoted him having said that nature is one and infinite, and undefined.[1] This quote demonstrates how Anaximander perceived nature in an overall light. This view is very indicative of his further philosophy. If nature is one and infinite, that means that it could have a multitude of things within it, but is required to stay cohesively together. To describe it as undefined takes it even further perhaps implying that we could never fully understand it or its potential. In another case, Simplicius quotes Anaximander as saying that "the source of things that have not been made yet must come from the same place as things that have been destroyed, out of necessity...".[2] This could mean that the substance that makes things must be coming from the same place that they are going to. This, in combination with what he said

[1] Simplicius *In phys.* 24, 26-30 (Kirk, Raven and Schofield 1957)
[2] Simplicius *In phys* 24, 17 (Kirk, Raven and Schofield 1957)

about the overall state of nature, allows us to say thus far that Anaximander would most likely agree with the statement that nature works in an eternal loop of recycling what has been into what will be. This concept of a single thing making everything and existing as the initial and final state is what Anaximander described as the *apeiron*, and is further supported by quotes of Anaximander from different sources. Hippolytus states that he claimed the material principle of existing things was some nature coming under the heading of the *apeiron*, from which the heavens and world came.[3] This quote can be understood similar to the ones already discussed, where Anaximander was simply attributing the fact that anything can exist at all to the fact that it existed in the indefinite. For nature to fall under the *apeiron* would mean that it perpetually always was and always would be, and that all of it came from the same place that the heavens and the earth came from; the origin of all things.

Although this concept of nature coming from what was and what has always been seems to be somewhat intimidating, it works very well with what later philosophers had to say on the subject. Aristotle claimed that to fully understand the natural world we had to assume the existence of non-material substances.[4] In this case a non-material substance is simply something that most likely exists, and works like a tangible material, but is non-tangible. The idea that it is non-tangible is what makes it a non-material substance rather than a material one. This non-material substance could be the same substance that Anaximander was suggesting was being recycled into new pieces of nature. However, it is more likely that this non-material and the substances Anaximander was referencing worked together, while being

[3] Hippolutus *Ref.* I, 6, 1-2; DK 12AII (Kirk, Raven and Schofield 1957)
[4] Curd and Graham, *Presocratic Philosophy,* page 507

separate concepts. At the time of Aristotle, this could have simply meant assuming that there were things that they did not understand, or that they could not see at the time. There are many aspects of the scientific world that we now have access to that would have been unattainable at the time of Aristotle. This includes things such as basic understanding of the periodic table, or the concept of living organisms such as bacteria. However, Aristotle could also have intended for non-material substances to be taken more abstractly, and meant something more along the lines of accepting that at a certain point a substance exists rather than understanding its actuality, or physical and tangible properties. An example of this in our modern understanding could be energy, which we cannot see, but through other substances can measure and know exists. Both Thales (Anaximander's mentor) and Anaximander were of the opinion that all things came from a single element. For Thales this element was water and for Anaximander it was a more abstract idea of the interaction between fire and water.[5] Later, Aristotle demonstrated the persistence of this idea through philosophical generations when he stated that "all the physicists make the infinite a property of some other nature belonging to the so-called elements, such as water or air or that which is intermediate between these".[6] This showed a movement from emphasis on something that could be seen and touched and understood to an emphasis on a stage in between two physically understood concepts. This idea continued into modern science where it was then supported with empirical evidence.

There are multiple examples of an inclination in nature towards cyclical processes as discussed by Anaximander and other philosophers. These can be found largely in the discipline

[5] Long, *Early Greek Phil.* Pg. 47
[6] Aristotle, *phys*, 4,203a16 (Long 1999)

of biology, and specifically in biochemical reactions. The most notable of these being the tricarboxylic acid cycle. This cycle is present not only in eukaryotic cells but also in prokaryotic and bacterial cells. The tricarboxylic acid cycle, or TCA cycle as it will be referred to in this paper, propagates itself by ending with the creation of oxaloacetate, which is then combined with Acetyl CoA and used to begin the cycle again.[7] This cycle is used by cells to produce ATP which the cell then uses to fuel the TCA cycle, as well as other processes and cellular growth. This allows the cell to maximize its energy production and use as much of its resources as possible. This cyclical process is an example of how nature follows the general process of recycling products and reactants between one another. In some cases, these products become the reactants for other processes within the organism. All of these chemicals feeding into the creation of one another in a loop as well as the feeding of these products into other cycles are examples of how in the biological sciences Anaximander's *apeiron* theory of everything feeding back to whence it came and being part of an indefinite whole is again applicable. This goes even further if we look deeper into what these chemicals are, and what makes them up.

Understanding that on this earth, these cyclical processes are present in chemical reactions, an even more detailed parallel of the understanding of the *apeiron* to modern physics can occur. Our modern English word "atom" comes from the Greek word "atomos" meaning "not sliceable".[8] For much of the history of physics, the atom was thought to be the smallest particle possible. Since the discovery of the atom however, scientists have found that the atom is actually composed of more elementary particles. It is from this that we now have

[7] Berg et al, *Biochemistry* 2015, pg 514
[8] Serway and Vuille, *College Physics,* 2015, pg 4

our understanding of the atomic structure of different particles. Much of this research was done by Danish Scientist Niels Bohr, and is often referred to as the Bohr model.[9] What this model demonstrates is that an atom is very similar to our solar system, with the nucleus being alike to the sun and electrons alike to planets. This was then further studied by chemists and physicist alike, and the nucleus was discovered to be composed of neutrons and protons, which have a neutral charge and a positive charge respectively. The number of protons is unique to each element and thus can be used to identify what element that nucleus is.[10] Even more recently, this was taken to an even smaller frame of thought and quarks were identified as existing (as far as we know) in 6 states; up, down, strange, charm, bottom, and top. These quarks make up protons, neutrons, and many other particles.[11] How do quarks, electrons, protons, neutrons, and elements make up the world as we know it? Using energy in the system they combine with one another to make elements and then elements combine together to create shape and form.

Now knowing, on a general level, what makes up the universe, and that on its most basic level, it required energy to exist, scientists questioned how this could work. What laws to they follow? Can we quantify it? Does it follow the same laws on all occasions or does it vary? These questions drove physicists to further investigate the world around them. In many, if not all cases, this comes back to a basic understanding of energy. In an isolated system, energy can be transferred and transformed between mechanical, chemical, and electromagnetic energy, among other forms. However, even though it is constantly being transformed, the total amount

[9] Serway and Vuille, *College Physics,* 2015, pg 4
[10] Serway and Vuille, *College Physics,* 2015, pg 4
[11] Serway and Vuille, *College Physics,* 2015, pg 5

of energy in a closed system never changes. It will always add up to be the same before and after.[12] This idea can be identified as the first law of thermodynamics; energy can neither be created nor destroyed.[13] If energy can neither be created nor destroyed, and is just constantly in flux between where it is and how it's being used then it would be in line with how Anaximander is quoted as describing the source of things; "the source of things that have not been made yet must come from the same place as things that have been destroyed, out of necessity…"[14] Therefore, it can be reasonably concluded that if physicists would be willing to accept that energy alone was the source of all things, then they would be able to agree with what we can understand Anaximander to be saying. However, in more recent studies about not only the origin of the universe itself but also the most elementary sub-atomic particles there has been some debate over whether energy content or wave function of a particle should be used to define a particle.[15] This definition is usually resolved and defined differently depending on which branch of physics is using it. Quantum Mechanics defines it in terms of wave function since that has been shown to relate directly to physical behavior. Since there is debate within its own field of study, there could potentially be too much discontent for physics as a whole to agree with Anaximander based on energy being the thing making up all other things.

A paper written by Dr. Grahame Blackwell and published in 2011 discussed unifying the two known types of physical entity created during the big bang. If this were to be done, it could potentially resolve what discontent there was between disciplines of physics. Blackwell defined

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[12] Serway and Vuille, *College Physics,* 2015, pg 127
[13] Serway and Vuille, *College Physics,* 2015,pg 406
[14] Simplicius *In phys* 24, 17 (Kirk, Raven and Schofield 1957)
[15] Blackwell, *Ele. Sub-atomic.,* 2011

these two types of physical entities as "photons of electromagnetic energy and elementary particles from which all matter is formed."[16] In his paper, he proposes that because it is understood that photons are absorbed by particles of matter to create an atom and also exist as free energy (energy that can be converted into work) it would not seem far off that these two supposedly different things actually exist as separate manifestations of the same phenomenon.[17] Blackwell claims that what we now know as "particles" exist in an adaption to and evolution from the big bang wherein there were constant bursts of energy, and anything that existed would have necessarily been able to adapt to energy changes. Patterns of electron flow around a nucleus have, since their discovery in the 1920's, provided us with a basic understanding of how electromagnetic waves constructed spin and static charge around said nucleus. Variance in electron energy levels put off different wavelengths that are often interpreted as light, but can also just be the off-put of free energy into a system, especially when dropping from an excited state to a lower one. If wavelengths are created from energy, this draws a parallel back to the aforementioned discussion of energy being the most basic unit, while still making up everything. A modern understanding of the *apeiron*. If Blackwell's theory could be proved, and accepted by physics as a whole, this would allow there to be without a doubt modern support for the defined *apeiron*.

Using this understanding of both Anaximander's theory, and modern physics, it is easy to see where they agree with one another. Both parties would agree that there is a singular thing at the center of all others, and that it is the source of creation as well as the end point for

[16] Blackwell, *Ele. Sub-atomic.,* 2011
[17] Blackwell, *Ele. Sub-atomic.,* 2011

that same thing . For Anaximander this may be an abstract concept of just a “something” that may or may not be defined. In the case of modern physics, this could simply be the concept of energy as it creates the smallest elementary particles that we know of at this time, which in consequence, make up everything else. Further than this, physics has even defined that in a closed system, such as our solar system, energy can be neither created nor destroyed and therefore all energy is recycled through different systems and processes. This agrees with what Anaximander is claimed to have described where all things must come from the same source of all things that have been destroyed. So much of modern science is understanding that almost all things work in a cyclical fashion, and the most current understanding of the source of all energy in our system now is the big bang, which was set off by a large input of what is referred to as primordial energy into a smaller system causing it to expand significantly.[18] Physical as well as biological processes tend to use their own products in either a separate cycle or within the same cycle they are produced in. As Anaximander said, this is out of necessity. If energy could be destroyed, there would have to be an infinite source of input into the system and that would be impractical to find, and maintain. Thus, the universe has laws that must be followed to continue functioning.

Physics as well as biology are full of cyclical processes or patterns wherein the products are then used as the reactants. In the case of biology this is most evident when looking at energy production and the tricarboxylic acid (TCA) cycle in particular. Similar to processes across biology, the TCA cycle works by taking energy input and using a set of reactants to start. The output of this cycle is energy molecules as well as compounds that are then used as the

[18] Blackwell, *Ele. Sub-atomic.,* 2011

reactants to begin the process again. Looking at this abstractly, it can be taken that the reactants are one and the same as the products. Thus, as Anaximander said, “the source of things that have not been made yet must come from the same place as things that have been destroyed”. This is further, and perhaps more clearly, shown in the field of physics when looking at what is considered the most basic unit of our known world. Physicists searched for this for years, going down from atoms to nuclei to protons and neutrons and eventually quarks. Quarks were then defined by the wavelength they give off and thus the energy. From this we can gather that at this point, energy can be considered the most essential in the universe. This energy has been defined by thermodynamics to exist perpetually since the big bang. It can be neither created nor destroyed. Energy can be shaped, manipulated, and change throughout its existence but it will always persist. It will feed from one thing to another causing creation or destruction of different chemicals, organisms, or even light. This allows us to truly see on a large scale what modern science would see Anaximander’s theory to be in practice.

Understanding what Anaximander was trying to say in his own time comes from looking at how he was quoted as well as how philosophy developed after him. This brings his ideas down to the most likely boiling point of how even if the universe is infinite and one, that must mean that it simply is all made up of the same thing being recycled over and over again. Essentially, everything is made of the same stuff at its core, and that stuff, whatever it may be, is present always. Modern science works parallel to this not only in biology, but in chemistry as well as physics. Thus it can be concluded that when looking at the world around us, the more we come to understand its functions, the more it seems to align itself with Anaximander’s theory with

energy being neither created nor destroyed, and the everything goes back from whence it came.

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