Irrigating Blood: Plato on the Circulatory System, the Cosmos, and Elemental Motion

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ABSTRACT This article concerns the so-called irrigation system in the *Timaeus*'s biology (77a–81e), which replenishes our body's tissues with resources from food delivered as blood. I argue that this system functions mainly by the natural like-to-like motion of the elements and that the circulation of blood is an important case study of Plato's physics. We are forced to revise the view that the elements attract their like. Instead, similar elements merely tend to coalesce with each other in virtue of their tactile features as the atomists describe. The notion of attraction is replaced with this notion of mere coalescence. I begin by outlining how blood is made from food. I then argue that an understanding of health and disease compels us to read Plato as if he were an atomist and to abandon the popular scholarly interpretations according to which the elements attract each other.

KEYWORDS Plato, *Timaeus*, biology, blood, physics, circulation

AT *TIMAEUS* 69A–B, TIMAEUS ANNOUNCES that it is time to complete his speech, making use of the kinds of causes—the true causes and *sunaitia*—to illustrate the cooperation between the divine and the necessary.[1] What follows is, among other things, an obscure account of the creation of the whole human being, from the mortal kinds of soul to the fingernails. The lower gods, who are doing this creative work at the behest of the Demiurge, confront numerous problems, including the fact that the human body is wasting away under the relentless barrage of the four so-called elements: earth, water, air, and fire. This is an unfortunate by-product of a solution to an earlier problem: when the Demiurge was creating the world and the lower gods, he combined the four elements using indissoluble bonds, including friendship (32c), such that their bodies could not come undone unless he willed

[1]All translations of Plato here are my own and use the Greek text from Burnet, *Platonis Opera*. I have consulted the translations in the bibliography, most notably Cooper and Hutchinson, *Complete Works*; and Lamb, *Plato in Twelve Volumes*. Translations of Aristotle are from Barnes, *Complete Works*.

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it; when the lower gods are creating human bodies, in contrast, they have access only to the four elements, and therefore they bind the elements together using the elements themselves (42e–43d). The result is an imperfect body, one that is always being depleted.[2]

Timaeus introduces the lower gods' solution to this problem starting at *Timaeus* 77c: a complicated irrigation (*hydraugōgia*) system, likened to a set of water pipes in a garden, designed to distribute the appropriate elements to the appropriate part of the body.[3] The idea seems to be that, for instance, if we lose a bit of earth from our neck, this irrigation system brings earth to the neck; if we lose water from our ankle, water goes to the ankle. The four elements are distributed throughout the body by the blood in our veins. This article is about this irrigation system, which uses the anatomy and some of the physiology of what today we call the *circulatory* or *cardiovascular* system. In the *Timaeus*, however, there is no clear distinction between the various systems of the body, and the functioning of the irrigation system depends as well on what we would call the digestive and respiratory systems, which Plato jointly likens, enigmatically, to a fish-trap (*kurtos*).[4]

The problem that Plato must solve, in the first place, is that it is deeply mysterious how blood can move from the bottom of the body to the top.[5] We shall see that blood is made in our belly, and yet it somehow replenishes even the topmost parts of our bodies. This is a real difficulty for the ancient Greeks, who in the classical period were ignorant of involuntary muscular contractions, such as the pumping of blood by the heart, and the distinction between veins and arteries. This is what I call *the hydraulics problem*. The second problem is to figure out how the bloodstream distributes the appropriate element to the appropriate part of the body. I call this *the replenishment problem*. Both problems will be solved by applying a principle from cosmology: namely, that the elements move toward what they are like. For instance, fire moves toward fire.

This article has two focuses: the first is understanding how Plato solves these problems in biology; the second is using the irrigation system as a case study of this central cosmological principle. Timaeus does say, at the end of this discussion, that the motion of the blood imitates the motions of the elements in the cosmos and that our body is like a cosmos in its own right (81a–b). When we take this into consideration, we shall be forced to revise the current scholarly understanding of the principle that like is *attracted* to like. Specifically, the major interpretations today, surveyed below, hypothesize that elements pull at or attract their like, but we shall see that this renders both health and disease inexplicable. Understanding

[2]Campbell ("Tomb," 120–24) argues that the lower gods are always trying to shore up problems that arise from the imperfection of their materials, and that their solutions are, in turn, always imperfect.

[3]Such an irrigation system is an important part of the laws governing farming life in *Laws* VIII (cf. 845d–e).

[4]I agree with Schroeder ("Replenishment," 338), who argues that we should think of this complex of systems as one large *replenishment system*; however, she holds that it is wrong to think of Plato as providing a solution to a problem in hydraulics (340n32). In saying so, she opposes Cornford, who argues that Plato is here "formulating the mechanical problem of hydraulics" (*Cosmology*, 306). We shall see in great detail below the *Timaeus*'s complicated solution to problems in hydraulics.

[5]Cf. Cornford's helpful illustration: "the body is like a house with a cistern on the ground floor. If all unconscious and reflex muscular action is completely ignored, how is the water to be driven up a pipe to the attics, so that it may descend again to the rooms?" (*Cosmology*, 304).

circulation requires reading Plato as if he were an atomist, believing that elements coalesce on account of tactile features such as their shape and size.[6] It is terribly difficult, in contrast, to explain the replenishment of a lack (e.g. of earth) in terms of an attraction between the earth being transported in our blood and the earth in our tissues, when it is the precisely the *lack of earth* that needs to be corrected.

Moreover, we shall see that reason (*nous*) and necessity cooperate in the cosmos not by working together on every single thing but by having two different spheres of activity altogether: the lower gods design the structures of our bodies (i.e. anatomy), whereas necessity—exemplified here by the principles of motion in the cosmos—governs the functioning of those structures (i.e. physiology).[7] The gods build our bodies, and they make them work by taking advantage of the way that the elements move and coalesce. I push back on the view that necessity is responsible only for those limitations that the cosmic *nous* has to accommodate in its creative work.[8]

An important disclaimer is that the fish-trap that is at the center of the digestive and respiratory systems will be discussed as little as possible. It is unavoidable at times precisely for the reason that Plato introduces it: its functioning helps turn food into blood and helps the food-blood leave the belly. However, a defect of today's scholarly understanding of Plato's biology as presented at *Timaeus* 77a–81e is that the fish-trap has gotten a disproportionate amount of attention.[9] Only rarely in this article will I take issue with what scholars have said about the fish-trap. For the most part, I want to make sense of how blood moves throughout the body, bracketing questions about how digestion creates blood beyond the basic details. Furthermore, we shall have an opportunity at the end to consider Plato's account of bodily diseases. For Plato explains (at least some kinds of) disease in terms of the natural workings of circulation being reversed or disrupted (83a, 83e).

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[6]I do not think that Plato is an atomist. Brisson and Ofman ("Anti-atomism") argue that it is misleading to associate Plato with atomism and that nobody in antiquity associated the *Timaeus* with atomism. I take it that part of being an atomist is believing that things are made up of atoms and void; Plato, however, denies the existence of void (*Tim.* 79b–c) and thinks that there are things that could not possibly be made of atoms (e.g. the Forms). An anonymous reviewer puts my point well: "in cases like circulation, structural features of the elemental particles familiar from atomist theories will best explain how Plato's elemental particles interact under the influence of necessity."

[7]See Pelavski, "Digestion," 62, for a similar approach to digestion and respiration. However, I add a caveat: I do not want to give the impression that the two spheres of activity are rigidly demarcated. For instance, necessity no doubt influences anatomical structures insofar as some of the features of the constituent particles that comprise them are due to necessity; the very cooperation between *nous* and necessity that the *Timaeus* describes is evidence that the boundaries are sometimes overstepped. Nevertheless, Plato's biology is such that *nous* does *not* create the rules that govern physiology, even though it is deeply involved in anatomy; to this extent, there are these two spheres of activity.

[8]Let me emphasize that this is not the only sense in which necessity operates in Plato's biology (i.e. it does not merely provide physiology). For instance, Johansen (*Natural*, 105) gives the example of bone's *brittleness* and *inflexibility* being necessary: the gods cannot change the features of bone; instead, they *have* to work around them and accommodate them. This is an example of the way that necessity is involved in anatomy, since the properties of anatomical structures (e.g. bones) are due to necessity.

[9]Pelavski, "Digestion"; and Schroeder, "Replenishment," are two clear examples of this trend. They admirably study their object, but their object sadly does not much include the irrigation system. Pelavski in particular *reduces* the circulation of the blood to digestion, which is a mistake.

1. CREATING BLOOD FROM FOOD

The most immediate problem for Plato to solve at *Timaeus* 77a–81e is how our bodies are replenished after being depleted by the environment. He presents three bodily systems to facilitate this: the circulatory (irrigation) system, the respiratory system, and the digestive system. These are presented in ring composition, where the outermost ring concerns the general need for replenishment (77a), the second ring concerns the irrigation system, the third ring concerns the respiratory system, and then the innermost ring concerns the digestive system. After the digestive system has been explained, Plato then revisits respiration and irrigation, and comments on depletion and natural death in light of what he has just explained (81e).[10]

Respiration and digestion are key to understanding irrigation. The reason is that these two systems work together to produce blood. Plato believed that blood is cut-up food. The earliest evidence for this view is in Homer's *Iliad*: Diomedes strikes Aphrodite, who bleeds not blood but "the ichor that courses through their veins, the blessed gods—they eat no bread, they drink no shining wine, and so the gods are bloodless, so we call them deathless" (V.381–84).[11] The gods eat ambrosia, not food, which means that they do not have blood but ichor. Plato's innovation is to explain how food becomes blood by appealing to his own account of physics.[12] Fire, which is composed of sharp tetrahedra, cuts up the food as it reaches our belly and turns it into blood. The fruits and vegetables that apparently compose humanity's natural diet at first become multicolored blood, since our diet has a diverse set of colors, but the reddish fire has stained it, explaining why our blood is mostly red (80d–e).[13]

The food is cut up in our bellies. The belly exists at the center of the fish-trap (*kurtos*) that Timaeus describes. It is deeply unclear what is meant by the analogy

[10]See Pelavski, "Digestion," 62, for more on the composition of this passage, though he does not account for the role of 81c–e in the importance of the outer textual ring. Schroeder ("Replenishment," 341–42) has a brief yet helpful breakdown of the passage. Both commentators miss that this passage must be read as symmetrical with the discussion of bodily disease that begins right afterward at 82a. Prince ("Disease," 908–9) correctly diagnoses mistakes such as this as why Plato's discussion of disease is often regarded as inconsistent or barely unified. Below, I disagree with Prince's interpretation of the passage, but I take his larger point: it behooves us as readers to notice the unity here. Bodily disease is characterized by Plato as a *reversal* of the normal processes of replenishment and irrigation (83a, 83e). It is in this sense that the passages are symmetrical: the discussion of replenishment establishes the uptake of necessary resources by the body in the manner that produces health; the following discussion establishes the way in which *the disordered uptake of resources* results in disease. This fact should weigh on how we work out the details of circulation. See Rivaud, *Oeuvres*, 114; and A. Taylor, *Commentary*, 591, 608, for two important criticisms of an apparent lack of unity.

[11]This translation is by Robert Fagles in Homer, *Iliad*.

[12]Aristotle, for instance, shares the same general understanding of blood as transformed food, though he adds to it his own evidence. For instance, he argues that blood is transformed food on the grounds that we have less blood when we are eating less food and more blood when we are eating more food (*PA* II.3, 650a31). In general, he thinks that blood is food that has been concocted in the heart and transformed into matter for our body (II.4, 651a13–15). Blood is potentially our body's tissues, just as water is potentially a plant and bricks potentially a house (III.5, 668a13–27).

[13]Plato discusses his theory of colors and the role that fire plays in their constitution at 67c–68d, with a mention of the color of blood specifically at 68b. (This is in addition to his claim at 80e that fire dyes blood red.) Yet, we do need to mention that some blood does have other colors: e.g. diseased blood is said to be multicolored (83a). This is due to the presence of bile, which is itself multicolored.

between this part of our anatomy and a fish-trap.[14] At a minimum, the fish-trap is a network of air and fire that exists at least partially in our bodies. The fire exists in the center of the fish-trap, where there is also some air; the outer shell of the fish-trap is composed almost entirely of air. There are two entrances (*enkurtiai*) into the center of the fish-trap.[15] These entrances are the nose and the mouth. The mouth-entrance is itself divided into two: one for eating, the other for breathing.[16] The nose, meanwhile, functions only as an entrance for air. These are the only dedicated entrances. Still, we have to account for the fact that air can pass through the pores of our skin, since the octahedra that compose air are subtle enough to move through these small channels, even though the food that we eat cannot similarly leak through. For this reason, there is another way out of the fish-trap, which is available only to the subtle particles of air and fire: namely, through the skin. Plato therefore believes that some of our breathing is done through the skin, which scholars generally refer to as *transpiration*.[17]

This seems to be a point in favor of the older scholarly interpretation of the fish-trap as partly existing outside our body.[18] Indeed, Plato does say that the gods "took

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[14]Much of the scholarly debate here concerns the nature of the analogy between a fish-trap and whatever Plato is describing here. The two camps can be roughly traced back to Cornford, *Cosmology*; and A. Taylor, *Commentary*. Cornford argues that Plato is using the image of a fish-trap in place of a diagram: nothing in the structure being described *functions* as a fish-trap, but the network of air and fire *resembles* the outline of this object (308). In contrast, A. Taylor prefers to understand the fish-trap analogy as a description of the *mechanisms* that are at work: specifically, this structure keeps the food in our bellies (548). Schroeder also helpfully points out, against Cornford's view, that "it may be worth noting that we are not explicitly invited to visualize a fish trap, unlike elsewhere in Plato . . . rather, Timaeus simply starts using fish trap vocabulary to distinguish and refer to parts of the analogous system in and around the human body" ("Replenishment," 232n15). Plus, it is hard to deny that Plato *is* talking about food being contained, or trapped, in the belly, as Tracy (*Mean*, 115–16) discusses. Schroeder ("Replenishment," 22) thinks that it is *fire* inside us that is the analogue to the trapped fish, with which I disagree since the fire is not trapped at all but escapes with the breath.

[15]Since '*enkurtia*' is a hapax legomenon, found only in the *Timaeus* and in Galen's discussion of this passage, the referent of '*enkurtia*' is unclear and controversial. I follow the modern tradition, inaugurated by Cornford (*Cosmology*, 308–12), that the *enkurtiai* are two entrances to one large fish-trap, with one of the entrances being subdivided into two. Lisi (*Timeo*, 125), Longrigg (*Rational*, 136–39), Pelavski ("Digestion"), Schroeder ("Replenishment"), and Velasquez (*Timeo*, 204) take this view. I take it that Brisson (*Timée, Critias*) also prefers this view, since he translates *enkurtia* as *entonnoir*. A. Taylor prefers a view, developed by Galen, that the *enkurtiai* are two smaller fish-traps nested within one larger fish-trap, saying that it "cannot be far wrong" (*Commentary*, 549).

[16]I follow Cornford (*Cosmology*) in this identification, against some others, such as A. Taylor (*Commentary*, 549), and Pelavski ("Digestion"). While Pelavski ("Digestion," 64) holds, as I do, that the *enkurtiai* are entrances to the fish-trap, he thinks that they are the upper airway (nose, mouth, nasopharynx, oropharynx, and larynx) and lower airway (trachea, bronchi, and lungs), which empty into the digestive tract (oesophagus and stomach). While this is not the place for me to argue at length against this interpretation, I agree with Longrigg that "Plato's knowledge of internal anatomy is of a very low order and is patently not based upon any human, or even animal, dissection" (*Rational*, 135). Pelavski ("Digestion") attributes to Plato an implausibly thorough understanding of human anatomy.

[17]Sometimes it is also called "skin-breathing" by e.g. King (*Hippocrates*, 226), who discusses this form of breathing with reference to the medical tradition of the womb moving throughout a woman's body and affecting her ability to breathe properly (225–28), a tradition that Plato participates in (cf. *Timaeus* 91c). Plato's view of transpiration is mostly likely inherited from Empedocles (DK 31B100). For more on Empedocles on transpiration, see Furley and Wilkie, *Respiration*, 3–5.

[18]Cornford (*Cosmology*, 313) argues that the fish-trap includes a "coat of air enveloping the trunk." This was the dominant position until Pelavski ("Digestion," 67) challenged it, convincing, among others, Betegh ("Illness," 250n43). I do take it that the argument regarding Plato's use of the word *peri* in

this thing [i.e. the fish-trap] and placed it around [*periestēsen*] the living animal" (78c), and also that they caused the "outer part of the fish-trap to grow around [*peri*] as much of our body as is hollow [i.e. the torso]" (78d). The conclusion, drawn by, among others, Francis Cornford, is that the fish-trap is a network of air and fire that partly sits around our upper body.

The workings of the fish-trap create blood. To understand how, we need to grasp two principles of motion in Plato's physics. The first is that whatever is made up of smaller parts can pass through what is made of larger parts, but whatever is made of larger parts cannot pass through what is made of smaller parts (78a–b). For instance, fire is made of smaller parts than air; therefore, fire can pass through air.[19] However, the cubes that compose earth are larger than the octahedra that compose air; therefore, earth cannot pass through air. Fire and air are the smallest, so they can pass through water and earth. This is why our bodies can hold in food but transpire air and fire through the pores in our skin (78a–b).

The second principle is that all motion occurs in a plenum. Plato had announced this principle earlier in the *Timaeus* but now emphasizes it here (79a–b) and uses it to explain respiration. Think about the air that is sitting over our torso: we exhale air from our nostrils and mouth, displacing the air around our torso, pushing it into what has just become empty, namely, the insides of our body. The displaced air enters through our skin. Since there is no void and the cosmos is crowded with the elements, when something moves, it displaces something else from the location that it moves into, pushing the displaced thing back into the now-vacant spot.[20] This process is called *periōsis*, a difficult word to translate but whose standard translation is 'circular thrust.'[21] When we inhale air, we similarly push the air inside

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this context, discussed in the main text, is a point in favor of the older reading; however, see Pelavski, "Digestion," 67, for his criticism. In addition to Pelavski's criticism, an anonymous reviewer makes an analogy with the ribcage: the fish-trap might enclose the hollow parts of the body while being inside the body just as the ribcage encloses things internal to the body without existing outside the skin. I take the point, but I think that it matters for our understanding of the fish-trap that the air being exhaled is in a constant exchange with the environment; given this feature of respiration, I see no reason in the text for drawing the boundaries of the fish-trap at the skin. The air in the environment is as much part of the fish-trap as the air in the body.

[19]Plato always speaks as if it is an invariable law that fire is the smallest and earth is the largest, but at *Timaeus* 57c–d, he explains that there is, in fact, an indefinite variety of sizes since the constituent triangles that make up the surfaces of the elements vary in size. (See Cornford, *Cosmology*, 230–39, for a discussion of the geometry.) It is apparently only a general truth that fire is the smallest. Nevertheless, it is still an exceptionless rule of physics that whatever has larger parts cannot pass through whatever has smaller parts. The fact that sometimes the elements come in different sizes helps to explain why the interactions of the elements will sometimes produce different rules, e.g. fire is sometimes extinguished by water but other times binds with it to form oil. This will be expanded upon in the final section of the article when I argue that sometimes the elements do not do what we might predict or want them to do, resulting in disease.

[20]This is an account of motion that one might recognize from Aristotle's theory of projectile motion, and he uses the term '*antiperistasis*,' which is not used by Plato, to name what is happening here. The idea is that a projectile in motion displaces the air in front of it, pushing the air behind it to where it once was, and the air that has been pushed behind the projectile further propels it forward, where it displaces more air, and so on, thus accounting for how projectiles stay in motion. It is possible, too, that just as Aristotle is inspired by Plato, Plato is inheriting this idea from earlier thinkers, although the evidence is very unclear. See Guthrie, *History*, 147–48n1; Solmsen, *Comparison*, 142; and A. Taylor, *Commentary*, 558, for more on this possibility.

[21]This is Cornford's (*Cosmology*) translation of the term. Opsomer ("Platonic") translates it as 'pushing around.'

us out into the now-vacant spot around our torso: the inhaled air enters through our mouth or nostrils, displacing the air in our torso and pushing it through the skin out into the world.[22] We shall consider *why* there is a constant back-and-forth between exhalation and inhalation in the next section.

With these two principles in mind, we can understand how blood is made from food. The air that enters our bodies has fire in it; after all, the air is hot to some degree (78e–79a; 80d–e). The fire does not just sit there but instead oscillates with the breath. The activity of the fire is the first illustration of a crucial third principle of motion for Plato: like moves toward like. The fire wants to escape the body and join the fire that is outside, though the sense in which this is true needs to be unpacked (79d–e). Therefore, the fire follows (*sunepomenou*) (80d) the breath in the same process of inhalation and exhalation that Plato had previously likened to the turning of a wheel (79b–c). When we eat food, it goes to rest in the belly, and then the sharp tetrahedra that compose fire cut it up and turn it into blood.[23] This blood is filled with the resources from the food that can be used to replenish the damage done to our body by the environment—but first it needs to get around the body.

2. MOVING THE BLOOD AROUND

The blood moves through the irrigation system that the gods have designed for us. Firstly, I shall describe this irrigation system and its channels. Then, I shall discuss how the blood gets out of the belly, and then, how the blood is distributed to the right parts of the body, using the broad cosmological principle that like moves toward like. It is important to distinguish the steps of the process because the mechanism for getting the blood out of the belly is different from how the blood gets around the body.[24]

The gods cut two channels, called *veins* (*phlēbes*), through our bodies for the purposes of irrigation (77c–e). It might be that these two channels ultimately branch off into others, such that each extremity and digit can be serviced by this system; however, Plato only ever speaks of two veins, reflecting that we have a left and a right side of our body. The impression we get from the text, then, is that the two veins weave in and out of every finger and toe: first, a vein goes down our thumb, then it weaves into the next finger, and so on, rather than branching off into different veins.[25] These veins course down the spine, one on each side of the

[22]It is important for understanding the history of biology that Plato has committed himself to the view that *exhalation precedes inhalation*. Before we inhale any air with our mouths, we exhale air through our mouths and fill our torsos up with air this way. Plato was roundly criticized for this view in antiquity, first by Aristotle (*Juv.* 472b6–473a2).

[23]Natural deaths occur when the tetrahedra in us become so inefficient at their job that they cannot chop our food fast enough to replace the materials of our tissues that are gradually depleted (81b–e). See the discussion of natural death in Grams, "Medical," 165. Schroeder, ("Replenishment," 342) integrates Plato's account of natural death into our understanding of the fish-trap. See Johansen, "Nutrition," for a larger discussion of life in the *Timaeus*.

[24]No scholar I am aware of has ever made this distinction before. These two distinct steps get collapsed into each other in every extant scholarly treatment.

[25]If Plato is following Diogenes of Apollonia, who similarly thinks that there are two veins, one on each side of the spinal column, then this speaks in favor of thinking that the channels branch off, since, according to Aristotle (*HA* III.1, 511b30–512b9), Diogenes thinks this.

spinal column. In the head, the two crisscross each other, such that the veins from the right side go toward the left, and vice versa. These veins perform a second function in this case: the veins loop around the head in order that they, along with the skin, can keep the head attached to the body. The lack of sinews in the head create this danger, and the irrigation system keeps the head tied on (77e).[26] Earlier in the *Timaeus*, Plato had described the heart as that which ties the veins together and as a kind of spring of blood (70b). However, the heart is not once mentioned in 77a–81e, and it is hard to see what role it could be playing; it is entirely absent from the explanation of circulation.

The difficulty of observing these anatomical structures for Greek thinkers cannot be overstated. Aristotle, in the *History of Animals*, expresses his dissatisfaction with his predecessors over this point (III.2, 511b12–24). The problem, as Aristotle sees it, is that the veins collapse upon death, making it hard to use cadavers to trace the course of the circulatory system.[27] In living things, it is difficult because the veins are internal and hard to reach when something is still alive. When Aristotle reports the views of his predecessors, we see that Polybus believed that there are four pairs of veins (III.3, 512b14–513a8), whereas Diogenes of Apollonia thought there were only two veins (III.2, 511b30–512b10). Plato's view is more like Diogenes's than Polybus's in this respect. Aristotle also comments that many of his predecessors thought that this system of veins started in the head (III.3, 513a10–12). This also sounds like Plato's view, since he thinks that the veins flow downward parallel to the spinal column (77c–e).

At this point, it is customary to reflect on what the items in Plato's explanation of circulation correspond to. Perhaps he has in mind the aorta and vena cava.[28] Perhaps the two channels are the hepatic and splenic veins.[29] It is possible, however, that Plato has virtually no substantive knowledge of internal anatomy at all, and we run the risk of misinterpreting the text if we make what he says fit contemporary biology.[30] While I am sympathetic to the interpretation according to which Plato is merely ignorant of anatomy, I think that we should bear in mind the problem he is trying to solve. No Greek thinker before Praxagoras of Cos at the end of

[26]At 77e, Plato says that this design also ensures that sensations from each side of the body are registered by the whole body. How exactly this is accomplished is unclear. Presumably, this has something to do with Plato's view that the motions that are transmitted from our sense organs to the soul in an episode of perception are so transmitted through the bloodstream. The role of blood in Plato's theory of perception is discussed by Johansen ("Perceiving") and Sassi ("Awareness"). Campbell ("Tool," 9n7) discusses this point, too, although there is nothing decisive there about whether *all* perception is mediated by the blood.

[27]Aristotle's solution was to look at the bodies of animals that had been emaciated and then strangled, which apparently caused the veins to be engorged with blood and therefore more visible (*HA* III.3, 513a14–15).

[28]A. Taylor (*Commentary*, 545) maintains this.

[29]Cornford (*Cosmology*, 305) argues for this position. These two veins seem to have been what Diogenes of Apollonia was identifying; so, if we want to assimilate Plato's and Diogenes's views, then we might agree with Cornford.

[30]Again, I point to Longrigg's claim that "Plato's knowledge of internal anatomy is of a very low order and is patently not based upon any human, or even animal, dissection" (*Rational*, 135). Reading Plato charitably is laudable, but we *know* that his biology is false, and our job as scholars is to understand it, even if that requires granting that Plato is badly uninformed of anatomy.

the fourth century BC was aware of the distinction between veins and arteries.[31] No Greek thinker at this time was aware of involuntary muscular contractions (e.g. of the heart). Plato wants to explain how the irrigation system works, and he cannot appeal to the same physiological resources that today's biologists can. For this reason, it can be helpful to see Plato not as doing the same sort of thing as Diogenes of Apollonia, Polybus, and others, but as trying to solve in the first place a problem in hydraulics about how blood gets around (so that he can solve a larger problem about replenishment). These other thinkers were interested in producing a complete anatomy of the human being; Plato seems more interested in appealing to anatomy only to the extent required, in our sliver of the *Timaeus*, to explain the replenishment of the body. That is why when we compare Plato's account of circulation to those preserved in the *History of Animals*, we are struck by its austerity. Diogenes of Apollonia, for instance, takes care to describe the size of each vein, the many delicate branches as the veins course past the shin and through the feet, and so on—not Plato. It could well be that the paucity of details reflects Plato's ignorance, but it could be that he aims to solve a problem, not to give a complete account of anatomy. It could be both. Either way, it does not matter for the purposes of solving the problem whether one of the channels is the aorta or something else.

The first phase of circulation is the exit of the food-blood out of our belly and into the channels. This is the first problem of hydraulics that Plato encounters: since he does not think that the food-blood *leaks* out of our bellies and into the veins, we need some way of explaining how it can be *uplifted* out into the veins that run parallel to the spinal column. Plato twice explains how this happens:

> For whenever the internal fire [i.e. the fire at the center of the fish-trap] follows the breath to which it is attached, as it enters or exits [the body], it oscillates constantly back and forth, enters into the belly, grabs foods and drinks, dissolves them, cuts them into small bits [*kata smikra*], which it carries [*poreuetai*] and leads through the exits [*dia tōn exodōn*], depositing them into the veins as water from a spring is drawn into pipes. (78e–79a)

> The fire cuts up the food, and it rises as it follows the breath, and as it rises it fills the veins from the belly by pumping into them the cut-up particles. (80d)

The short version is that the food-blood gets caught in the motion of the fire as it tries to escape with the breath. The longer version of this explanation needs to account for *why* this happens as well as identify the exits that are mentioned in the first passage.

The identity of the exits is particularly enigmatic. The dominant interpretation today is that the exits are nothing but those regions of the fiery mesh in the fish-trap through which the food-blood passes on its way to the veins.[32] However, we

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[31] Even Praxagoras did not understand what he observed: he thought that air travelled in the arteries because he observed them only postmortem, when they were emptied of blood.

[32] See e.g. Pelavski, "Digestion," 69: "This pressure enables contact between the rays of fire in the mesh-like walls of the stomach, and the food and drink which have entered through one of the ἐγκύρτια, and made their way into the κύτος of the stomach. Such contact eventually leads to the digestion of nourishment and to the transference of small digested particles through the mesh towards the blood vessels." Joubaud (*Corps*, 67) posits subcutaneous "vies gazeuses invisibles" as ducts or airways in the fiery mesh. Pelavski follows suit while subtly modifying Joubaud's theory.

can rule this interpretation out on the grounds that the food-blood is too big to pass through fire or air.[33] The food-blood is made up of all the elements; this has to be the case because our body needs replenishment from all four elements. There is no way for earth or water to pass through fire or air. At first glance, it might seem possible that the process of digestion has broken down these elements into particles so small that they could fit through the fiery mesh at the center of the fish-trap, but I disagree: the particles cannot be *that* small since they make up blood.[34] Blood is thinner and less dense than some of the food we might have just eaten, but if blood could pass through fire, then so could some of the drink we just consumed. Therefore, when we identify the exits that the food-blood takes from the belly, we ought to bear in mind this important principle of elemental motion: things with larger parts cannot pass through things with smaller parts.[35]

For this reason, I identify the exits that the food-blood takes as mere entrances into the veins. Imagine that at the top of the belly, the veins that are coursing down the spinal column stop and open up into the belly, just as they must surely do at every part of the body that they irrigate. Now the fire that is carrying the food-blood up to the top of the belly as it oscillates with the air simply transfers the food-blood from the belly to the veins. The food-blood never needs to pass through fire or air, as it does according to the dominant interpretation today, but which is impossible due to the *Timaeus*'s physics. The fact that the exits are at the top of the belly guarantees that food could never escape the belly until it is lifted by the fire, which is a process identical to the process of cutting, since the fire chops the food into blood at the same time as picking it up. Therefore, we must also conclude that although the center of the fish-trap is fire, there are ways for the blood to move that do not involve passing *through* fire.

The other question is why the fire and air are oscillating at all. This is the same as a question left unanswered in the previous section: the question of why there is a cyclical process of exhalation and inhalation. To make sense of this, we need to discuss in greater detail the third and final principle of motion in Plato's physics: the principle that elements move like to like. The elements "naturally go to their own region [*ienai kata phusin eis tēn hautou khōran*] towards their like [*pros to sungenes*]" (79d). This is a complicated and difficult principle to interpret, so I suggest that we regard circulation as a case study: we will return to this principle shortly to interpret it more thoroughly. We shall see that a proper understanding of circulation complicates the two most popular scholarly interpretations today. Right now, let us observe that this explains why fire and air try to escape our body. We

[33] I am relying heavily on the *size* of the elements because that is how Plato articulates the relevant rule of physics (i.e. that things with *larger* parts cannot pass through things with *smaller* parts [78a–b]). However, when it comes to interactions between the elements, more counts than size alone; I discuss some of these tactile features and how the elements interact with each other later in the article.

[34] If the elements were reduced to the constituent triangles that make them up, to such a degree that fire were no longer fire but merely triangles, then circulation would not involve the like-to-like motion of elements, but Timaeus clearly states that it does. Therefore, cut-up food, as blood, needs to still be large enough to be made up of the recognizable elements.

[35] Lastly, it is worth pointing out that if the two channels do not, in fact, branch off into subchannels, it could not be otherwise than this explanation has it: the veins need to open up directly to receive the incoming blood.

breathe in these two elements, but they tend by nature to move toward their like. There are two ways out: through the pores of the skin or through the two *enkurtiai* in the head, namely, the mouth and the nose. There is a dense concentration of fire in us, such that air that enters our body is heated up by the fire that is inside. The consequence is that when air enters through the pores, for instance, it heats up and then escapes the way it entered. It escapes violently, displacing the air outside us and pushing this outside air into our body, where it would not otherwise go—but this is happening in a plenum, so there is no alternative. The air that enters our body is heated up by the dense concentration of fire, such that *it* then escapes, pushing the air outside us into our body. Thus does the cycle of respiration occur (79d–e).

Fire too is being moved with the oscillation of air. We learn this when we consider circulation and digestion, because the oscillation of fire is what chops up food and deposits the newly made blood into the two veins. The movement of these elements is inexplicable without appealing to the larger cosmological principle that like moves toward like. This principle is further invoked to explain how the appropriate tissues and organs in our bodies are appropriately replenished. This is the second and final stage of circulation.

Here is what Plato says about this episode:

> Both processes, replenishment and depletion, happen in accordance with the way that everything in the whole universe happens, which is that everything moves towards what is its like. For the environment around us always wastes away our bodies and distributes and sends off each part towards what shares its nature [*homophulon*]. Again, the things in the blood [*enaima*], having been cut up inside us and surrounded by the structure of an individual living thing as by the cosmos, are forced to imitate the motion of the cosmos: each of the cut-up parts inside moves towards its like [*sungenes*] and occupies the area that had just been emptied. (81a–b)

Much about this passage needs to be unpacked. Plato appeals to the principle that like moves toward like to explain how our body, being wasted away by the environment, is replenished. The idea appears to be that if we lose, say, some earth from our skin, earth that is being transported in the veins can be deposited there. In this way, the body behaves as the cosmos itself does: it is a frame or structure in which the elements move toward their like.

The problem is that it is deeply unclear how to make sense of this application or use of the like-to-like principle. There are two major interpretations. When the composition of the elements is discussed in great detail (54d–56c), the principle seems to be such that the elements move toward the largest concentration of their kindred in the cosmos, and this is the so-called *cosmic interpretation*, which is the most popular today.[36] This interpretation does a good job of explaining why fire and air rise: they are trying to make it to wherever in the cosmos the largest concentration of their kindred is. This is especially important because circulation, digestion, and respiration all rely on attempts by fire and air to escape the body. It does a good job of explaining why earth falls, on the assumption that the Earth is the largest concentration of earth in the cosmos. It is not so clear what is going

[36]For recent applications of this view, see Broadie, *Nature*, 267–68; Grams, "Medical," 165; and Johansen, *Natural*, 111–12.

on with water, though: it is not obvious where in the cosmos the largest supply of water is such that water falls to the ground no matter where someone is pouring it on Earth. Bear in mind that if we were standing next to the largest concentration of water in the cosmos with a bucket of water, Plato would *not* predict that the water would fly out of the bucket to rejoin the reservoir. Water cannot pass through air (since water has larger parts than air does), so the air keeps the water in the bucket at all times.

Further, the most obvious problem with the like-to-like principle overall is one for which Plato has a solution: if the elements want to aggregate, it needs to be explained why they have not already done so and why the cosmos is not already perfectly divided into four quadrants, each belonging to one of the elements. There are two forces preventing this (58a–c). The first is that the world, imbued with a soul and therefore with its own source of motion, has a natural tendency to push centripetally on the elements, thus constricting their motions. The second is that as the smaller elements pass through the larger ones to get to their kindred, they break up the larger elements. This means that there is elemental change as the elements move.

What the cosmic interpretation cannot explain, however, is circulation. The physiology of the circulatory system is such a valuable case study because it exposes what Plato cannot mean by the like-to-like principle. If earth always travels to the largest concentration of earth in the cosmos, then it will never be deposited in the tissue or organ in our body that needs the earth. The same goes for all the other elements, too. Earth would simply fall to the bottom of our body and make a futile attempt to exit through our feet. *The irrigation system would fail to solve the problem that it is designed to solve* because it would not explain how the elements, as ingredients in the blood, get around.

There is another interpretation of the like-to-like principle that was developed in the context of Plato's biological views. This is the so-called *living-being interpretation*.[37] According to this view, the elements move toward their kindred *within a living thing*, such that earth, for instance, does not attempt to escape the body. There is, however, an obvious problem with the living-being interpretation: it opposes the mechanics of respiration, which depend on air and fire both trying to and succeeding at escaping from the body. Without this action, both digestion and circulation fail, too.[38] Moreover, according to this interpretation, it is mysterious what is special about living things such that the central principle of motion in the cosmos singles them out in this way.[39]

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[37]See Prince, "Disease," for an articulation and defense of this view.

[38]Prince ("Disease," 925–26) has a reply to this objection. He says that the explanation of respiration "asks how the cyclical movements of inhalation and exhalation could have begun—not how they are maintained in a body already alive." However, I find this unconvincing because it does not address the fact that respiration and digestion continue to operate in this same manner even after life has started (and besides, respiration starts when life starts; it is not as if there is ever a time when we need to explain respiration for a body not yet alive). Prince ("Disease," 926) does allow for the cosmic interpretation to operate alongside the living-being interpretation in order to explain why fire and air would try to escape the body at all, but I do not think that he has convincingly explained respiration on his view.

[39]It is an important fact about Plato's view of nourishment and other bodily functions that they do not rely on the soul's activities. The relevant mechanisms use elemental motion, not psychic activities. See Johansen, "Nutrition," for a contrast between Plato and Aristotle on this point.

There are two things we should observe to properly understand circulation and, more generally, the like-to-like principle. To see the first, let us consider the replenishment of skin, which is comprised of earth and water (76a–c). If our skin is perfectly intact and has not lost any of its earth and water, then the bloodstream will pass it by; for there is no room for any of the ingredients of the blood to occupy, since the cosmos is a plenum. If it has lost some earth, then some of the ingredients of the blood will occupy that space because there cannot be a void. *The first mechanism of the distribution of blood is, after all,* periōsis *(circular thrust).* Indeed, Timaeus's account of circulation combines both the like-to-like principle and the workings of *periōsis*: "each of the cut-up parts inside moves towards its like [*sungenes*] and occupies the area that *had just been emptied* [*kenōthen*]" (81b, emphasis added).

Now let us consider replenishment of skin from a different perspective. The skin needs both water and earth to be healthy: we want to avoid having excessively dry or excessively moist skin. If we lose earth due to the environment, then we need to appeal to the like-to-like principle to explain why our skin is replenished with earth instead of with water. Neither the cosmic nor the living-being interpretation could explain why this happens. *Our skin is replenished with what it is lacking, not with what it already has.* If our skin is composed of a thousand units of earth and five-hundred units of water, and it loses one unit of water, then it stands to reason that, if like *attracts* like, earth would prefer to replenish the skin because the larger concentration of earth attracts it. The same goes for all organic tissue, including perhaps most importantly the marrow, which contains our soul and is put together in a perfect proportion of all the elements (73b–c).[40] A good account of Plato's theory of circulation ought to specify how these proportions can be preserved, such that if our tissue needs water, it is replenished with water.

To make sense of this, we need to overcome the tendency of both the cosmic and living-being interpretations to view elemental motions in the *Timaeus* purely as one bulk of elements *pulling* at or attracting some smaller amount.[41] We need to talk about how the elements *coalesce.* In fact, Plato's biology does not leave any room for thinking about a *pull* in the first place: if a bulk of earth pulls at one unit of earth, it is rendered mysterious why the tissues of our body are not separated into chunks of the elements; if the elements within our blood are pulled toward the largest bulks of the same kind of element in the cosmos, then the earth in our bloodstream, for instance, would just fall toward our lower body. As our tissues are deteriorated by the environment, eventually there would be nothing recognizable about the human body. We need to have an account of like-to-like motion that does away with *pulling.*

3. THE ATOMIST INTERPRETATION

We can see how this would work by looking at what Democritus and Leucippus thought. It is not part of my argument that Plato was familiar with these thinkers; rather, my point is just that we can see how like-to-like motion without pulling or

[40]For scholarly discussions of the marrow, see Fronterotta, "Anima," 146; Gregorić, "Humans," 189; Pradeau, "Moelle"; and Solmsen, "Tissues."

[41]Consider e.g. the view defended by Code that "like bits of matter are attracted to their own kind" ("Weight," 211).

attraction works if we consider their physics. Leucippus, for instance, thus describes the generation of worlds:

> The worlds come into being as follows: many bodies of all sorts of shapes move "by abscission from the infinite" into a great void; they come together with one another and revolving in all manner of ways, they begin to separate apart, like to like. (DK 68A40)[42]

Aristotle testifies that Leucippus and Democritus said that everything comes to be (*gignesthai*) by the intertwining (*sumplokē[i]*) and scattering (*peripalaxei*) of atoms (*De Caelo* 303a5–7). Simplicius too ascribes to them the belief that the atoms "collide and become entangled in such a way as to cling in close contact to one another" (*In De Caelo* 295.11).[43] Simplicius explains the idea of entanglement in this way:

> The reason he [i.e. Democritus] gives for atoms staying together for a while is the intertwining and mutual hold of the primary bodies [i.e. atoms]; for some of them are angular, some hooked, some concave, some convex, and indeed with countless other differences; so he thinks they cling to each other and stay together until such time as some stronger necessity comes from the surrounding and shakes and scatters them apart. (*In De Caelo* 295.18–24)[44]

Here we can grasp a better picture of what accounts for like-to-like motion in this physical system: it is not as if similar atoms *pull* at each other; rather, atoms with similar features *coalesce*. They get entangled. Elsewhere, Simplicius explains further that atoms "move in the infinite void . . . [and] become intertwined one with another according to the congruity of their shapes, size, positions, and arrangements, [such that they] stay together and so effect the coming into being of compound bodies" (*In De Caelo* 242.22–25).[45] We know that Democritus and Leucippus engaged in something similar to the geometrical project in Plato's *Timaeus*: after all, Aristotle recounts that they assigned shapes to the elements, although they failed to specify anything other than that fire is spherical (*De Caelo* 303a11–12). However, we need to see whether we can find in Plato's *Timaeus* some textual evidence to support unpacking like-to-like motion in the same way as Democritus and Leucippus.

In fact, we *can* find such textual evidence. One important passage contains the famous winnowing-basket image (52d–53c), in which it is said that the things in the receptacle "are winnowed out, as it were, like grain that is sifted by winnowing sieves or other tools; they are carried away and settle down, the dense and heavy ones in one direction, and the rare and light ones to another place" (52e). Here, Plato describes the motion of the receptacle before God added order to it.[46]

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[42]This translation is by Kirk, Raven, and Schofield, *Presocratics*, 417.

[43]This translation is by Kirk, Raven, and Schofield, *Presocratics*, 425.

[44]This translation is by Kirk, Raven, and Schofield, *Presocratics*, 426.

[45]This translation is by Kirk, Raven, and Schofield, *Presocratics*, 426.

[46]I use the temporal language of 'before,' but it is surely possible that Plato is not describing the state of the cosmos at any moment in time but is imagining what the cosmos would be like *without* God's order. (Plato uses the same language here: "before the universe was set in order" [53a].) This frames the winnowing-basket image as a criticism of fifth-century materialists, such that Plato is leveling the accusation that their view that the world comes to be out of mere interactions between the elements, with no intervention from an intellect, is senseless. This criticism is developed at greater length in *Laws* X, where Plato refutes the view that the arrangement of the elements is prior to intellect.

Specifically, there are a few things missing that God has yet to contribute: the first is the motion of the world-soul, which does not exist at all yet; the second is the shapes of the elements. The four elements must have *some* features at this stage, since Plato does speak about "four kinds" here (53a). Plus, he confirms that they have some vestiges (*ikhnē*) of the geometrical features that they will come to have when God gets his hands on them. In virtue of these vestiges, the elements are sorted out like to like, being sorted together as a winnowing basket sorts the dense together, and the rare together elsewhere.[47]

In this passage, Plato sounds like an atomist. He is describing the motion of like to like not on account of some *pull* between them but on account of their features, apparently mechanistically. The motions of a winnowing basket are such that all the heavy things, for instance, go to one area together in virtue of their heaviness. Furthermore, that God has not ordered the cosmos yet is evidence that God does not *create* like-to-like motion when he orders the cosmos: the Demiurge and his allies use this principle of motion when creating the human body, among other things, to facilitate circulation. It is a feature of the cosmos that hinges simply on there being elements that have some properties in the first place.

When Plato describes the world after it has been ordered by God and describes the triangles that make up the surfaces of the elements, he uses this account of their surfaces to explain the coming-to-be and dissolution of the objects that are familiar to us. For instance, he describes the way that earth is broken up by fire and cannot reform into other elements because the basic building blocks of cubes, which make up earth, do not fit with the building blocks of the other elements (56d). In contrast, water that is dissolved by fire or air can reform into either water again or into the combination of one unit of fire and one unit of air (56e). This is on account of the basic constituent polyhedrons that make up the elements.

Generally, Plato prefers this strategy of explaining interactions between things in the corporeal realm this way: consider the discussion of compounds of water and earth, such as wax and liquefiable stones, which he explains in terms of water and the gaps between the units that make up earth (60e–61b).[48] When he imagines someone attempting to forcibly remove earth from a large concentration of earth, he explains the heaviness of the earth in terms of its natural tendency to "cling to its like [*sungenous antekhomena*]" (63c–d). This word, '*antekhomena*,' we also observe in Simplicius's account of Democritus's view that atoms "cling [*antekhesthai*] to each other and stay together until such time as some stronger necessity comes from the surrounding and shakes and scatters them apart" (*In De Caelo* 295.22–24). We *could* explain this clinging the same way that many scholars do, such as by hypothesizing that "individual particles of an element, x, [have] a

[47]Scholars who research the atomists do a good job of articulating the point that they thought atoms interlock with each other *as if* there were some attraction or pull between atoms with the same features, when there really is no such force. See C. Taylor, "Atomists," 188, for discussion. Timaeus's winnowing-basket image highlights the same: these tools work *as if* there were an attraction when there is none. We see Plato say that the winnowing basket moves its contents by "pushing" them (53a), as opposed to the contents moving of their own accord by means of some attraction.

[48]E.g. in this part of the *Timaeus* (58a–61c), Plato explains a great variety of compounds, such as frost and saps, on account of the tactile features of their constituent parts and through such processes as condensation and compression. The size of the particles is the most prominent feature, but firmness, fineness, and solidity (59d, 60d) play important roles, too.

power tending to produce movement towards something else, y."[49] It is not that these suggestions make no sense or that they are otiose. Rather, it is that they are at odds with how Plato speaks about corporeal things: it is hard to see how a polyhedron could have this power to produce movement, and Plato prefers to explain the interactions between bulks of polyhedrons in terms of interactions between their parts and their tactile features.[50]

Supposing that elements have a natural power to *produce movement* is also at odds with Plato's theory that the soul is the source of motion. I suspect that scholars who take this view of elemental motion are, in a way, projecting backward the notion of Aristotelian natures onto Plato. It is profoundly mysterious and strange how some combination of triangles, when put together to form a tetrahedron, attracts other tetrahedra, yet when the same triangles form an octahedron, they attract octahedra instead. Accordingly, it seems to me that there is some attempt to read Aristotelian natures back into Plato, where these natures explain these behaviors. Yet, the theory of natures as well as the general view that corporeal things have a power to initiate motion in, attract, or pull other corporeal things are directly *what Plato is opposing* when he argues that bodies rely on the soul to initiate motion in the cosmos in *Laws* X.

The largest problem is that these suggestions—that there is in the polyhedrons a power to produce movement toward others of their same kind—simply do not explain what happens in the body's irrigation. This is the problem that this present article is focused on working out. However, if we hypothesize that like-to-like motion is merely the coalescence of shapes that fit with one another, then this does make sense. Imagine that bone is composed of ten units of earth and eight units of water; the bone then loses one unit of water due to the usual deterioration; the bloodstream can then supply the tissue with exactly what is missing: one unit of water. That is what fits there. The bone is shaped such that it can perfectly receive the unit of water; the polyhedrons that make up the bone can *catch* the unit of water as it passes by. If we tried to explain this replenishment in terms of some natural attraction between like and like, water would *never* go to a tissue that is mostly composed of earth. Moreover, it would be *impossible* for the healthy proportions of the elements in each tissue to be maintained. For if the so-called cosmic interpretation of elemental motion is correct, then earth should fall to the bottom of our bodies (and likewise each element should seek its like in the cosmos at large); if the living-being interpretation is correct, then the elements should be attracted to the largest concentration of each element in our bodies. Yet, our bodies do not have the four elements in distinct regions; rather, there is a healthy proportion of the elements spread throughout each tissue.

I emphasize *health* here because this explanation also accounts for disease. When discussing bodily diseases, Plato describes the natural order of things being reversed or disrupted. The bloodstream "no longer maintains the natural order of circulation [*taxin tōn kata phusin ouket' iskhonta periodōn*]" (83a). The bloodstream

[49]Prince, "Disease," 924.

[50]Mourelatos ("Atoms") offers a similar analysis of atomism and the explanation of properties in terms of the relationship between atoms.

is replenished in a way that is not "in keeping with nature" (83e). If there were an attraction between units of earth, for instance, then this would not be possible. If there is a natural tendency for like to attract like, it does not make sense to say that sometimes earth fails to attract earth, for instance, or that earth sometimes attracts water. *Just as the common interpretations fail to explain health, they also fail to explain disease.* However, according the atomistic view being defended here, this does make sense. Sometimes the tissue that is being replenished can receive water or air. Its health depends on its receiving water, not air, but Plato's physics does allow for air to be sometimes slotted where one might prefer water to go.[51] Explanations that render the bloodstream such that it can only deposit elements where they ought to go do not accommodate the remarks about disease and unnatural circulation. One important lesson to be learned from the discussion of diseases is that we need an account of elemental motion on which like sometimes does *not* settle with like, and this lesson again highlights the value of studying biology as a case study of cosmology.

Some passages in the *Timaeus* might tempt the reader to think that there is some pull in the elements toward their like. The first is when Plato talks about a region in the cosmos that has the greatest mass of fire in it, "towards which fire moves" (63b). The second is a case we have already seen in Plato's biology: the stage of replenishment during which fire escapes from our body, seeking its like in the cosmos, in the process of which it cuts up our food and turns it into blood. These two episodes make it seem that fire is being pulled toward its like in the cosmos. However, explaining these episodes does not require attributing this to Plato. Another explanation is that fire is set in motion either by the receptacle's shaking or by the motions of the world-soul, which, as we saw above, also acts on the elements (58a–c).[52] We do not need to posit a *pull* to explain fire's motions in these cases. Fire moves ceaselessly until it reaches its like because it needs something to cling to; otherwise, it cannot rest.[53] Plato is, therefore, committed to the principle that a *body in motion stays in motion unless or until it is acted upon by a force.* The result is what Plato says: fire moves toward its like. If fire encountered

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[51]At 87c–d, Plato explains that a healthy body is well proportioned. At 88d–e, he uses this observation to praise physical exercise, in which a person shakes his or her body, which, if done appropriately, ensures that the elements in the blood get distributed to the right place. The mere need for exercise to accomplish this effect illustrates that the elements are not guaranteed to always be distributed properly.

[52]One recalls Aristotle's question posed to Democritus regarding the atoms: "what is it that sets them moving?" (*GC* I.8, 326b2). The complaint is that Democritus does not specify the cause of the atoms' initial motions (or what keeps them in motion, since Aristotle believes that a body in motion requires a cause to *keep* it in motion). It is not impossible for Plato to simply leave the same question unanswered, but we *can* be charitable here and say that motions of the world initiate motion in the elements (possibly in conjunction with the motion of the receptacle, if indeed its motion persists once God has finished ordering the world). Aristotle's criticism is not the last word, either way. Bailey imagines a possible reply to Aristotle: "they are neither moved by an external force, nor do they move themselves; they are of their very nature for ever in motion; a force would be needed not to move them, but to stop them" (*Atomists*, 134n1). There is also a debate about whether we can explain the motions of atoms in terms of their weight or the centripetal motions of the cosmic whirl; see Furley, *Cosmic*, 91–102, for more discussion.

[53]Atomists, e.g. Epicurus (*Letter to Herodotus*, 61), think this, too. Balme ("Mechanism," 23) has a brief but interesting discussion of Aristotle's own incredulity concerning this principle of physics; Balme also discusses whether Democritus is committed to this principle.

earth along its way, for instance, it would be more likely to dissolve earth than to bind with it, since Plato repeatedly applies the principle that smaller particles move through and dissolve larger ones (56d–e, 58a–c).[54] In general, when Plato says that the elements move toward their like, we should read him as writing like a fifth-century materialist: fire, for instance, moves such that it will not stop moving until it reaches its like, to which it clings. We witness in the discussion of bodily diseases that Plato is not describing an invariable, exceptionless law of nature but only a natural tendency that can be violated.[55]

It must be pointed out, though, that Plato very frequently speaks about elemental motion *as though* he thinks that there is a pull or even that there is a natural place for each element. Sometimes this is the fault of translators. For instance, Plato once writes that "the void does not exist, and these bodies shove around into each other, and as they separate and combine, they exchange places, and each thing goes towards its seat [*pros tēn hautōn diameibomena hedran hekasta ienai panta*]" (80c). Plato is describing the fact that everything has to displace something else as it moves, given that there is no void. Other translators render the last clause differently. It is common to take the phrase '*pros hedran*' ('toward its seat') to be 'toward its own place.'[56] This is an overtranslation of the phrase and gives the impression that Plato believes in each element having a natural place.[57] What he means by 'its seat' is simply *where the thing ends up settling*. Sometimes water will settle with earth, thereby creating clay; other times, water will settle with other water, creating pools and lakes.

But Plato himself is sometimes responsible for this confusion, such as when, as we have seen, he says that there is a gathering of fire "toward which fire moves" (63b). Yet, consider what Democritus says:

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[54]Sometimes fire *does* bind with earth. It is true that smaller particles dissolve larger ones, but if this were the whole story, then we could not explain why earth acts as a barrier to erosion (e.g. in the construction of bone), since bone would virtually always be getting dissolved by fire. Plato explains that there is an "indefinite variety" of sizes among the elements (57c–d). We can still say, generally, that fire is smaller than earth, since fire has fewer surfaces and, therefore, tends to be smaller. (The variety of sizes among the elements is due to the variety of sizes among the constituent triangles that make up their surfaces.) The consequence is that the elements will sometimes behave differently depending on the sizes of the particles that are interacting with each other; e.g. sometimes water will extinguish fire, but other times, water and fire will bind together to create oil. Sometimes, fire will pass through and dissolve earth, and other times, they bind to form lava. This explains to some extent why disease comes about: there are cases where an extraordinarily small unit of earth exists and might end up where earth would normally not fit and definitely where it is not wanted in the body.

[55]At a glance, it might be tempting to say there is a force of *attraction* that can similarly be violated or overpowered. However, when we unpack what it might mean to violate or overpower a force of attraction, the idea ceases to make sense: there does not seem to be a force that could be responsible for the exceptions. In contrast, it makes sense to say that there is some slot in a bulk of elements that *tends* to receive only water but, in this case, due to the tactile features of the elements surrounding the slot or of the element being slotted there, water *or* earth could fit there.

[56]Donald Zeyl does this in Plato, *Timaeus*.

[57]Aristotle uses the term '*hedra*' in the *Meteorology* when criticizing Plato's account of oceans in the *Phaedo*'s eschatological myth (II.2, 356a4). The term there means something like water's "fixed place" or "fixed seat." I suspect, though cannot prove, that many of the interpretative problems concerning Plato's physics are generated by projecting Aristotelian philosophy (e.g. the meanings of such terms as '*hedra*,' and Aristotelian natures, as I mentioned briefly above) back onto Plato. Plato's use of '*hedra*' picks out where something tends to settle, not where something is fixed; the point of *Tim.* 80c is to describe corporeal things displacing and pushing things around, not being fixed.

> Creatures flock together with their kind, doves with doves, cranes with cranes, and so on. And the same happens even with inanimate things, as can be seen with seeds in a sieve and pebbles on the sea-shore. (DK 68B164)[58]

This passage is misleading: it gives the mistaken impression that Democritus thinks that there is some kind of attraction between like things. There is not, and when we dig into Democritus's view, we learn that although he initially talks about like-to-like motion as if there is an attraction, the details of his explanations reveal that there is no force of attraction. I maintain that something similar is happening with Plato: despite the way that he sometimes talks, the details of the interactions between corporeal things rule out there being a force of attraction or natural places for the elements. The value of human physiology as a case study of Plato's physics lies in this insight.

Plato's explanation of circulation is built on a view of elemental motion according to which no element has a particular motion. This is the sense in which Plato denies Aristotle's theory of natures. This denial frees up Plato to think that the elements go where they are needed in our body, instead of where they are supposed to go according to their nature. This, of course, turns him into a target for Aristotle's criticism in *De Caelo*. Specifically, Aristotle criticizes Plato's views concerning weight, heaviness, and the lack of directionality of each element's motions. These views fall outside the purview of this article; however, let us note that the lack of directionality is a virtue when it comes to explaining circulation. For there could not be the appropriate replenishment of tissues if the elements naturally veered in a certain direction.[59]

Plato's account resolves the problems with which we began. The *hydraulics* problem is solved thus: blood can move from the bottom of our body to the top because circulation is taking place in a plenum. Food enters our body and then becomes blood, which is uplifted by the motions of air and fire into the bloodstream. This new blood pushes the bloodstream forward. Our blood has nowhere to go but up through the channels of our body to the head and then back down. Imagine a pipe that runs up a wall and has an entrance at the bottom: one could make the water go up the wall by simply filling the pipe, since the water has nowhere else to go. This solution most immediately uses the principle that motion occurs in a plenum, but the uplifting of the newly created blood into the body's channels is facilitated by the oscillation of fire and air, which is based on the like-to-like principle. The *replenishment* problem is solved thus: as our tissues deteriorate, whatever fits is deposited from our blood into the right slot, because

[58]This translation is by Kirk, Raven, and Schofield, *Presocratics*, 420.

[59]Briefly, there are two accounts of weight and heaviness in the *Timaeus*. The first comes at 56b when Plato says that fire is the lightest of the elements because it is made up of the least number of like parts (i.e. it has the smallest number of surfaces). The second account comes at 62c–63e. The crux of this account is Plato's claim that an element "cling[s] to its like [*sungenous antekhomena*]" (63c–d). We explain this in the way laid out above: a bulk is composed of elements that have coalesced on account of their tactile geometrical properties, perhaps by slotting tightly into each other's interstices. The like-to-like principle, which features so centrally in the 62c–63e account of weight, explains the clinging of the parts of a bulk. Heaviness is what the agent experiences when trying to separate that bulk from its surrounding, forcing it "contrary to nature [*para phusin*]," by which Plato means that the agent is working against the tendency of some elements to settle with these other elements in this arrangement (63c). See Code, "Weight"; and O'Brien, *Theories*, for venerable treatments.

this process is happening in a plenum and therefore any empty space needs to be filled immediately. When *whatever fits* preserves the correct proportion of elements, our tissue is healthy; whenever not, it is diseased.

That this type of motion happens by necessity is indicated by the winnowing-basket image: it predates the Demiurge's involvement in the world.[60] The image shows, among other things, that the cosmos *simply and necessarily is such that like things coalesce together*. When Plato explains how the Demiurge creates the world using *sunaitia* as tools, he says, "such being the nature of all these things by necessity [*ex anankēs*], the craftsman of all the most beautiful and best things took them over [*paralambanein*] when he was producing the self-sufficient and most perfect god" (68e). The verb '*paralambanein*' is a helpful illustration of how the divine *nous* relates to the motions of necessity: necessity is not merely the source of limitations that the Demiurge must work around. The motions of necessity, such as elemental motion, are taken over and redirected toward the good.

Consider the following passage from *Laws* X:

> Soul drives [*agei*] all things in heaven, on Earth, and in the sea, by means of its own motions, which go by the names of wish, examination, taking-care, deliberation, true and false belief, joy, grief, courage, fear, love, hatred, and all the prime-working [*prōtourgoi*] motions akin to these that take over [*paralambanousai*] the secondary-working motions of bodies, such as increase, decrease, separation, combination, and those that follow these, such as heat, cold, roughness, smoothness, white, black, bitter, and sweet, all of which the soul uses, when it both cooperates with divine understanding [*noun*] and guides everything, as a true deity, happily and correctly, or when it pairs with the lack of understanding [*anoia(i)*], it brings about the opposite. (896e–897b)[61]

Here again we see the language of *paralambanein* to describe the way the soul's intelligent motions take over and redirect the preexisting motions of bodies.[62] The *Timaeus*'s discussions of biology in general and the physiology of the respiratory and circulatory systems in particular illustrate that the basic, necessary motions of the cosmos are preserved in the ordered world.[63] The winnowing-basket image

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[60]Because Plato says that like-to-like motion predates God's arrangement of the world, he and Democritus do agree to an extent on what a world without an intelligent cause would be like. (They disagree, of course, to the extent that Plato does not think that Democritus can explain *order* and rational motions.) Both thinkers believe that in a world without an intelligent cause, there would be like-to-like motion. Democritus seems to have intended his account of like-to-like motion in terms of atoms' tactile features to explain arrangements without an intelligent source of order; see Furley, *Cosmic*, 79, for more discussion.

[61]There is some debate about the identity of the subject of the first sentence (and thus the whole passage). In the Greek, there is no definite article attached to the subject. Carone ("Evil," 283) argues that the soul talked about here is the world-soul. See Campbell, "Self-Motion," 527, for an argument that this passage is about soul generically.

[62]Cf. the initial description of the Demiurge's creative activity: "For God wished that, as much as possible, everything would be good and nothing evil, when he took over [*paralabōn*] as much as was visible, which was not at rest but was moving in a discordant and disorderly way" (*Tim.* 30a).

[63]Consider Plutarch, who says that "just as a man skilled in attunement and rhythm is expected not to create sound or movement either but to make sound tuneful and movement rhythmical, so god did not himself create either the tangibility and resistance of body or the imagination and motivity of soul, but he took over [*paralabōn*] both the principles [*arkhas*]" (*On the Generation of the Soul in the* Timaeus 1014B). He is using the same language of *paralambanein* to get at the important idea that craftspeople do not create the material that they are working with but instead shape it toward their

from the *Timaeus* highlights the early days of the principle that will later come to ensure the survival of our bodies.

Francis Cornford seems frustrated when he complains that, in Plato's physics, like things "come together on the principle, unanalysed (here [i.e. in the winnowing-basket image] as elsewhere) and assumed as obvious, that like things do come together."[64] It is true that Plato does assume this principle, and its unanalyzability might speak to the fact that it is a basic and necessary part of the cosmos, but we can make some headway in understanding it by thinking through the greatest and most prominent application of the principle in the *Timaeus*: the irrigation system, which no pulling or attraction can explain. An account of coalescence that is similar to Democritus and Leucippus's account does suffice, however. Moreover, we can appreciate the ingenuity of the lower gods, who used the motions of necessity to facilitate the physiology of the anatomical structures that they had devised.[65]

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desired product. (Perhaps a better example is that of a statue-maker, who does not *make the clay* but instead merely takes it over and turns it into a statue.)

[64]Cornford, *Cosmology*, 202. See also Cornford's claim that this principle of elemental motion is "an ultimate unexplained assumption" (169). While I agree that there is no outright *argument* for the like-to-like principle, I think that it is sufficiently well-illustrated by the countless examples of elements coalescing on account of their tactile features to form the objects familiar to us in our lives (58a–61d).

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