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Aristotle and Scientific Experiments

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ABSTRACT: Many have argued that there is no room for experiments in Aristotle's natural science: experiments intervene in nature, but Aristotle holds that we must simply observe nature; if we intervened, the result would be something artificial or contrary to nature. Against this, I argue that Aristotle not only performed experiments, but also holds that there is much about nature that can be discovered experimentally.

RÉSUMÉ : Beaucoup ont soutenu qu'il n'y a pas de place pour des expériences scientifiques dans les sciences naturelles d'Aristote : les expériences interviennent dans la nature, mais Aristote soutient que nous devons simplement observer la nature; si nous intervenions, le résultat serait quelque chose d'artificiel ou contraire à la nature. Contre cela, je soutiens qu'Aristote a non seulement effectué des expériences scientifiques, mais a également maintenu qu'il y a beaucoup de connaissances sur la nature qui peuvent être découvertes expérimentalement.

Keywords: ancient philosophy, Aristotle, scientific experiments, nature, natural change

1. Introduction

It is frequently argued that Aristotle had no natural science — in particular, no physics or mechanics — because he performed no experiments.[1] This absence,

[1] S. Sambursky, *The Physical World of the Greeks*, xii; T.S. Kuhn, "Mathematical versus Experimental Traditions in the Development of Physical Science," 55, writes:

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it is argued, is not by accident: Aristotle performed no experiments because he thought there was no room for them in natural science. Experiments require us to intervene in nature so as to manipulate causal processes; in G.W. Leibniz's summary of Francis Bacon's new method, to know nature, we must put it on the rack.[2] Aristotle, it is argued, held the opposite view: scientific inquiry requires us to stand back and watch the natures of things reveal themselves.[3] If we intervened, the result would be either something artificial, reflecting merely the results of our own agency, or would do violence to nature by forcing bodies to behave contrary to their nature. Either way, experiments cannot show us what happens by nature.

The trouble with this view is that it is wrong about Aristotle's account of both the theory and practice of natural science, for: 1) he did perform experiments, most notably in investigating the nature of saltwater; and 2) he holds that there is much about the behaviour of perceptible objects that can be discovered experimentally. In the following, I argue for these two claims by considering, first, the experiments that Aristotle performed, and second, where for him the

(continued)

"While the tradition governing scientific explanation [going back to Aristotle] demanded the specification of formal causes or essences, only data provided by the natural course of events could be relevant to it. To experiment or to constrain nature was to do it violence, thus hiding the role of the 'natures' or forms, which made things what they were." H.D.P. Lee argues that the Greeks observed, but did not experiment; thus, their approach was rational, but non-scientific: "Introduction," Aristotle's *Meteorologica*, xxvii.

[2] G.W. Leibniz, "Letter to G. Wagner," *Philosophical Papers and Letters*, 465; *GP* VII, 518. Bacon himself speaks of "constraining," "forming," and "vexing" nature (Latin: *constringere*, *fingere*, *vexare*): *De dignitate et augmentis scientiarum*, 1.496, 500. For two modern scholars who, while disagreeing about how much violence toward nature is implicit in Bacon's account of experiments, nevertheless agree that for Bacon the "vexing" of nature in experiments causes motions that Aristotle would consider to be contrary to nature, see C. Merchant, "'The Violence of Impediments': Francis Bacon and the Origins of Experimentation"; and P. Pesic, "Francis Bacon, Violence, and Experiment: The Aristotelian Background." Interestingly, Bacon himself puts experiments in the category of artificially produced events, not those that do violence to nature: *De dignitate et augmentis scientiarum*, 1.496.

[3] S. Waterlow, *Nature, Change, and Agency in Aristotle's* Physics, 35, 95, writes that Aristotle is only interested in the specific nature of natural substances, not the properties that belong to all physical objects. The specific nature of a natural substance, in turn, is expressed by that substance's natural motion, its change toward its purpose or natural end. Since natural motion, for Aristotle, is self-caused, human intervention would only get in the way of natural substances expressing their nature.

human manipulation of causal processes can reveal the nature of physical objects, including natural substances. Having defended these two claims, I conclude by considering the implications of this account for Aristotle's distinction between artifacts and natural substances.

2. Aristotle's Experiments

The clearest example of Aristotle's use of experiments is found in his discussion of saltwater and the origin of its salinity. The general question he considers here is whether the natural state of water is as saltwater, not fresh water.[4] After all, the great bulk of water seems to be in the sea as saltwater, and seawater occupies what is for Aristotle the natural place of water. Thus, saltwater seems to be the natural condition of water, and so saltwater, not fresh water, should be considered to be the fourth sublunary element. Aristotle argues against this view because he holds that saltwater is itself a compound of other, more primitive elements, one of them being fresh water. To show this, he performed two procedures to separate the salt from seawater: distillation and filtration. He describes his experiment with distillation as follows: "We will say, having tested it, that saltwater, when evaporated, forms fresh water, and the vapour does not, when it condenses, condense into seawater again."[5] The purest form of water, then, is fresh water. This result is confirmed by distilling wine and other liquids; they too are revealed to be compounds of water and earth because, when distilled, they too condense back to fresh water, leaving a separate earthy compound as a residue.[6] The method of filtration gives the same result: "That saltiness consists in an admixture is evident not only from what has now been said but also if one makes a jar of wax and puts it in the sea, having fastened its mouth in such a way as to prevent the sea getting in; the water that gets through the wax will be fresh water, the earthy part causing the saltiness through admixture being separated as though through a filter."[7] The upshot of these two experiments, according to Aristotle, is that saltwater is salty because of the admixture of an earthy compound to fresh water. Saltwater is not the most primitive form of water because it is itself compounded from more primitive substances, namely water and, ultimately, earth.

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[4] *Mete*. II 2, 354b1–18. Following Liddell and Scott, I use the following abbreviations for the works of Aristotle: *APo*. = *Analytica Posteriora*; *Cael*. = *de Caelo*; *de An*. = *de Anima*; *EN* = *Ethica Nicomachea*; *GA* = *de Generatione Animalium*; *GC* = *de Generatione et Corruptione*; *HA* = *Historia Animalium*; *Metaph*. = *Metaphysica*; *Mete*. = *Meteorologica*; *PA* = *de Partibus Animalium*; *Ph*. = *Physica*.

[5] *Mete*. II 3, 358b16–18.

[6] *Mete*. II 3, 358b18–23.

[7] *Mete*. II 3, 358b34–359a5. The method described is an example of what we would now call 'reverse osmosis'; the latter is the method used in most water desalination plants today.

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Further evidence for this view is provided by examining its physical consequences. If saltwater is a compound of water and earth, then it must be denser than fresh water by itself. This prediction is confirmed by several observations: ships float higher in saltwater than in fresh water, as do eggs and humans.[8] Moreover, this method of analysis can be applied to other liquids, with the same result: when liquids as diverse as wine, urine, whey, honey, milk, and blood are distilled, they too are discovered to contain various admixtures of water and earth and to vary in density as a result.[9] Given these results, Aristotle concludes that saltwater is denser than fresh water and must contain an element that is denser than water, namely earth.

For our purpose, what is significant about these experiments is that the result is not undermined by having been artificially produced. As Aristotle describes them, in these experiments, human intervention isolates a causal connection between the amount of earth mixed into certain liquids (the independent variable) and their resulting density (the dependent variable). There is nothing about this result that depends upon its being artificially produced; both distillation — through evaporation and condensation — and filtration take place in nature and produce the same result as when these processes are humanly controlled. Aristotle sees no relevant difference in the way in which these artificial and natural processes separate earth and water in these liquids; they also show the same relation between the amount of earth in a liquid and its resulting density. Thus, Aristotle's results in these experiments are replicable in two ways: both by other humans and naturally.

Aristotle sets out other claims about nature that are established by human intervention. Air is a distinct corporeal element, he argues, and not just the absence of other elements, because we can use it to inflate a wine skin or trap it in a water siphon between bodies of water.[10] A void or rare mixture of other elements, he argues, could not produce these effects. Similarly, heating and cooling cause physical bodies to solidify or liquify, regardless of whether the heating and cooling are done by humans or by non-human physical agents. Aristotle describes, for example, an experiment in which he mixes the yolks and whites from several birds' eggs and then gently warms the mixture.[11] The warming causes the mixture to disaggregate: the yolks conglomerate with other yolks and then soften, while the whites conglomerate with other whites and then harden. Here and in similar experiments using different substances, Aristotle tries to show that this kind of separation and conglomeration through heating and cooling results from the difference in composition of the substances tested. In the case of the birds' eggs, for example, he argues that the yolk and white are not just coloured differently but also differ in their material composition; the latter

[8] *Mete*. II 3, 359a5–14.

[9] *Mete*. IV 7, 384a3–18.

[10] *Ph*. IV 6, 213a25–31.

[11] *HA* VI 3, 560a20–b3; *GA* III 1, 752a1–8.

is shown by the fact that the parts of these substances behave differently when heated.[12] More generally, the solidification and liquefaction that take place in material substances as a result of heating and cooling are explained by the elements out of which these substances are made. Again, it does not matter whether the heating and cooling are naturally or artificially produced, or whether the physical substances being heated or cooled are naturally occurring objects such as plants, animals, and their bones and sinews, or artifacts such as earthenware cooking vessels and the foods produced in them; the results are the same, and they depend only on the material composition of the substances involved.[13]

A few more examples illustrate the broad range of natural properties that Aristotle investigates by replicating them artificially. With respect to colour, he holds that the variation in colour of animals' eyes is a function of the depth and transparency of the fluid in them.[14] This is an instance of a more general pattern: as the depth of a transparent fluid varies, so does the resulting colour we see. Once again, this pattern occurs both artificially and naturally, whether in a cooking vessel or in the sea. Another example is Aristotle's explanation of rainbows; he argues that the colours of the rainbow are produced by light being reflected by droplets of water in the air, which act as tiny mirrors.[15] The same rainbow-like reflections are seen when an oar is lifted out of the sea, causing the water falling from it to reflect light in different colours, or when water falls from above in such a way as to pass from darkness to light.[16] These are all instances of the same pattern of interaction between light and water. The same invariability is also seen in the properties of sound: the difference in pitch in the voices of animals is caused in the same way as the change in pitch in the strings of musical instruments; as the tension in the strings varies by tightening or loosening them, so does the pitch of the sound produced when the strings are struck.[17] Once again, natural and artificial cases behave in the same way: the same tightening or loosening produces changes in the pitch of animals' voices. Similarly, thunder is understood by looking at the loud explosive sound produced by humans pouring water on fire.[18]

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12 *Mete*. IV 1, 378b20–25; Chapters 4–6, especially 4, 381b23–382a3; 5, 382a22–b1; 10, 388a10–29; *PA* II 2, 649a30–34.

13 On these processes, see G. Freudenthal, *Aristotle's Theory of Material Substance: Heat and Pneuma, Form and Soul*, 150–178.

14 *GA* V 1, 779b13–35.

15 *Mete*. III 4, 373b19–33.

16 *Mete*. III 4, 374a29–b7.

17 *GA* V 7, 787b20–26, 788a3–10, 17–24; *Cael.* II 9, 290b30–291a28. At *GA* V 1, 778a16–b19, V 8, 789b20–22, Aristotle argues that features of animals such as their eye and hair colour as well as the pitch of their voice is due to material necessity and not to their formal or final causes.

18 *APo*. II 11, 94b32–37.

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In all of the above cases, human intervention is irrelevant to the causal processes under investigation. Indeed, the constancy of the processes under consideration is so great that Aristotle also uses what is perhaps the ultimate form of human manipulation in experiments, namely thought experiments: he argues that a body set in motion in a void would continue moving *ad infinitum*, in a straight line and at a constant speed, unless impeded by another, larger body.[19] He then argues that this motion — which we would call 'inertial motion' — never actually takes place because every physical body has a natural motion, which prevents it from behaving in the way described in the thought experiment.[20] Once again, however, the presupposition of Aristotle's claim is that certain types of behaviour found in physical objects are invariable in both naturally and humanly caused situations. Human intervention in these cases does not hide nature but reveals it by replicating natural processes.

3. Human Agents as Natural Causes

One might object that some of these examples are not actual experiments because Aristotle has not adequately isolated and controlled the natural substances involved, say, the water droplets in a rainbow or the eyes and vocal chords of animals; replication of natural processes is not enough, only direct manipulation of these natural substances will suffice.[21] In the above cases, however, Aristotle holds that there is no relevant difference between what is artificially produced and what occurs naturally: the causal mechanism being investigated behaves in the same way whether it is initiated by a human or a non-human agent. In effect, the human agents here are behaving in the same way as natural agents. In the production of these processes, human agents are just as natural as any other physical agent.

Now, in one sense the claim that human agents sometimes act in the same way as natural substances is trivially true; humans act like natural substances because we *are* natural substances. Nevertheless, it could be the case that humans differ from all other natural substances in the way in which we exercise our causal capacities, and Aristotle sometimes speaks this way: humans are rational beings, and rational capacities are fundamentally different from non-rational capacities in that the former have the power to produce opposites, whereas the latter cannot; humans can apply both heat and cold to a body, but hot bodies can only heat other bodies when they come in contact with them.[22] As a result, human causal

[19] *Ph*. IV 8, 215a19–22; *Cael*. III 2, 301b2–4.

[20] *Ph*. IV 8, 215a1–14; *Cael*. III 2, 300b9–17. On the principle of inertial motion and Aristotle's physics, see C. Byrne, *Aristotle's Science of Matter and Motion*, 20–22.

[21] L. Bourgey, for example, argues that Aristotle's trials with saltwater and heating egg mixtures constitute real experiments, but that the other cases are merely arguments by analogy: "Observation and Experiment in Analogical Explanation."

[22] *Metaph*. IX 2, 1046a36–b24; 5, 1048b5–11.

agency requires a choice by the human agent to determine which opposite will be realized; no choice is involved in the exercise of non-rational capacities.

Sometimes, however, human agents cause an effect in the same way as non-human natural substances, without choice or reason. Such is the case when human agents produce an effect simply by virtue of the physical matter common to the agent and the object on which it is acting. All perceptible objects, according to Aristotle, whether artificial or natural, are ultimately made out of the same material elements.[23] All material elements, in turn, have causal capacities that operate in them uniformly and invariably, for example, the heating and cooling of bodies discussed above.[24] These causal capacities also operate in everything made from the elements, namely the rest of the perceptible universe, because all other perceptible objects are made from these elements and depend upon their causal properties.[25] Thus, the basic causal capacities of the elements govern the behaviour of perceptible objects everywhere, regardless of whether that behaviour is produced by nature or humans. It also does not matter if the object being moved is an artifact or if it is naturally occurring; human artifacts are still subject to the laws of matter. Matter behaves everywhere in the same way, and the physical necessity governing its behaviour never stops operating in the perceptible objects made from it, whether natural or artificial.

This invariability across all perceptible objects, Aristotle holds, is due not just to the universal presence of the material elements, but also to the way in which perceptible objects cause change. For Aristotle, all efficient causality is ultimately exercised by contact between physical bodies; there is no action at a distance.[26] Whatever else is involved, the exercise of a causal capacity in perceptible objects requires one body pushing or pulling on another.[27] In this pushing or pulling, there is necessarily a proportion between cause and effect, regardless of whether the change is produced naturally or artificially.[28] This

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[23] *Cael*. III 3, 302a16–28; *GC* I 5, 320b12–14; II 1, 329a8–13, 24–32.

[24] Another example is the natural motions of the elements: *Cael*. I 2, 268b15–24; 9, 278b22–279a5; III 3, 302b5–9; *Ph*. IV 1, 208b8–21. These motions are simply necessary because the elements always move this way and cannot move otherwise: *APo*. II 12, 96a2–5; *Ph*. II 9, 199b34–200a5, 30–32; VIII 1, 252a17–19; *Cael*. IV 2, 308b12–15; 4, 311b14–19; *GC* II 11, 338a17–b11; *PA* I 1, 642a33–b4; *EN* II 1, 1103a18–23.

[25] For example, all physical objects move naturally to or within the natural place of the element from which they are predominantly made: *Cael*. I 2, 269a1–2; IV 4, 311a30–b8; *GC* II 8, 334b31–34.

[26] *Ph*. III 2, 202a3–9; VII 1, 242b59–63; 2, 243a32–35, 243a11–244b2; VIII 5, 256b18–20, 258a20–21; *GA* II 1, 734a3–5; 4, 740b22–741a4.

[27] *Ph*. VII 2, 243a11–244b2.

[28] *Ph*. VII 5, 249b27–250a28; VIII 10, 266a26–28; *Cael*. I 7, 275a2–10; III 2, 301b4–6; *GA* II 1, 732a19–20.

proportionality between cause and effect is the basis for Aristotle's laws of motion.[29] These laws deal with the quantifiable relations between three factors: the causal powers that act on a body, the amount of change that these powers produce, and the amount of time that the resulting change takes. Here Aristotle argues that the amount of change in the object being moved will be in direct proportion to the amount of power applied to it by the agent, and in inverse proportion to the resistance to that change, which comes from the quantity of the body being moved and the density of the physical medium through which it is moving.[30] These proportions hold for all causal agents and all bodies moved by them, whether natural or artificial, because they belong to all movable objects simply as physical bodies.

The important point here is that a motion does not become violent and unnatural just because it has been caused by a human being. The distinction between natural and violent motion is grounded in the body being moved, not the mover: a motion is natural if it is in accordance with the intrinsic nature of the body in motion; that intrinsic nature expresses itself in the motion or change that the body in question causes in itself.[31] If an external body moves another body in accordance with the natural motion of the latter, it is irrelevant whether that external mover is a human or non-human agent. If, for example, the downward natural motion of a heavy body is accelerated by a human being or a gust of wind, the resulting motion is still natural.[32] Similarly, if an external body moves another body contrary to the natural motion of the latter, again, it does not matter whether that external mover is a human or non-human agent; if a

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[29] The most extensive modern treatment of these proportions is found in I.E. Drabkin, "Notes on the Laws of Motion in Aristotle." See also I.B. Cohen, *The Birth of a New Physics*, 2nd edition, 15–22; G.E.L. Owen, "Aristotelian Mechanics"; E. Hussey, "Aristotle's Mathematical Physics: A Reconstruction"; S. Berryman, *Mechanical Hypothesis in Ancient Greek Natural Philosophy*, 97–103; C. Byrne, *Aristotle's Science of Matter and Motion*, 28–36.

[30] I.B. Cohen, *The Birth of a New Physics*, 19, captures this relation with the formula V (velocity) is proportional to F (force) divided by R (resistance); E. Hussey, "Aristotle's Mathematical Physics," 215, sums up these several proportions as an equation between the power of the agent times the temporal length of the change, on the one hand, and a constant times the amount of change and the size of the changing thing (adjusted for relative density), on the other.

[31] *Ph*. II 1, 192b8–19, 193a29–30; *Cael*. I 2, 268b16; III 2, 301b18–19; *de An*. II 1, 412b15–17; *GA* II 1, 735a2–5; *Metaph*. V 4, 1015a13–15; IX 8, 1049b5–10.

[32] *Cael*. III 2, 301b17–30; *Ph*. VIII 4, 254b33–255b31. At *Ph*. V 6, 230b23–25, Aristotle says that a body typically accelerates in its motion to its natural place, whereas violent motion decelerates. If the motion of a body accelerates, even naturally, there must be some force acting on it.

heavy body is thrown upward, that motion is violent, regardless of whether the cause is a human being or something natural, such as the wind.

In sum, at the level of the physical matter from which they are made, the causal powers exercised by human agents and non-human physical agents are the same, and they produce the same effects in the object affected by them, whether that be an artifact or a natural substance. All physical objects have the same basic physical capacities. Humans act in a distinctive way, unlike other natural substances, when we exercise our rational capacities through choice. At the level of our physical matter, however, humans cause change in the same way as other natural substances because, in the end, there is only one way to produce change in another physical object: through physical contact in accordance with the causal proportions discussed above. All these causal relations can be investigated experimentally because, at the level of matter, nature does not distinguish between human and non-human agents; here all agents are natural agents.

4. Conclusion: Distinction between Artifacts and Natural Substances

We have seen that there is a great deal of room for experiments in Aristotle's natural science; at the level of their matter, all perceptible objects behave in the same way. Given this uniformity, we need to reconsider Aristotle's distinction between artifacts and natural substances. Aristotle grounds this distinction in the ability for self-motion: natural substances can move or change themselves; artifacts, insofar as they are artifacts, cannot.[33] The qualification that artifacts cannot move themselves insofar as they are artifacts is required because there is something natural about all artifacts, namely the raw materials from which they are ultimately made.[34] These natural raw materials retain their ability to move themselves. Thus, every artifact is capable of natural motion and change by virtue of what is natural about it; it is the artificial part of it, namely its formal cause, that is inert.

The difference between artifacts and natural substances, then, is grounded in their respective formal causes. In addition to the capacities for self-motion that belong to all physical objects because of their raw materials, natural substances possess a second set of capacities to move or change themselves because of their formal cause. Stated differently, natural substances have two natures, one due to their formal cause and another due to their material cause.[35] Artifacts possess no such second set of capacities for self-motion. This inertness is hardly surprising; the artificial part of artifacts, the formal cause that we have added, is made by us

[33] *Ph*. II 1, 192b8–34, 193a29–30; 7, 198a27–b1; *Cael*. I 2, 268b16; *de An*. II 1, 412b15–17; *GA* II 1, 735a2–5; *Metaph*. V 4, 1015a13–15; VI 1, 1025b18–21; IX 8, 1049b5–10; XII 3, 1070a7–8.

[34] *Ph*. II 1, 192b16–20.

[35] *Ph*. II 2, 194a16 (δύο αἱ φύσεις), 22–7; 8, 199a30–2.

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in such a way that we can move them in certain ways. We do not want artifacts to move themselves in certain ways precisely so that they will move as we wish; we want them to be useful to us, not useful to themselves.[36]

Thus, where human intervention would prevent a natural substance from exercising the distinctive causal capacities it possesses by virtue of its formal cause, human experiments will not work; one cannot study the migratory patterns of birds by putting them in cages. At the level of their physical matter, however, all perceptible objects are indifferent to the distinction between artifacts and natural substances. At the level of physical matter, human interventions act just like natural causes. Thus, to the extent that the behaviour of natural substances is due to the physical matter from which they are made, human manipulation of these capacities in experiments can reveal their nature, not hide or distort it.

[36] Thus, Aristotle distinguishes between the ruling human art that determines the formal cause and function of an artifact, and the producing art, which must know its material cause as well; the latter is subordinate to the former: *Ph*. II 2, 194a36–b7; 7, 198a22–7; 9, 199b34–200a7.

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