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SCIENTIFIC METHOD IN *METEOROLOGY* IV

Tiberiu Popa

This article explores the main aspects of Aristotle's scientific method in *Meteorology* IV. Dispositional properties such as solidifiability or combustibility play a dominant role in *Meteor.* IV (*a*) in virtue of their central place in the generic division of homoeomers, based on successive differentiation and multiple differentiae, and (*b*) in virtue of their role in revealing otherwise undetectable characteristics of uniform materials (composition and physical structure). While Aristotle often starts with accounts of ingredients and their ratio (e.g., solids that contain a significant amount of water are liquefiable), the natural direction of his investigation is from observations regarding dispositional properties and their manifestation to accounts of composition and microstructure. Such passages tend to be easily syllogizable, a feature that—along with the criteria that shape his method of division—argues, I believe, for the compatibility of *Meteor.* IV with Aristotle's theory of scientific inquiry. The concluding sections of my article deal more succinctly with reputable opinions and final causation in *Meteor.* IV.1–11 and with the relation between this treatise and Aristotle's biological corpus.

Introduction

Aristotle's attempt in *Meteorology* IV to outline a virtually new scientific domain is an impressive feat, comparable—on a more modest scale—with his effort to

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I would like to express my deep gratitude to Mary Louise Gill and to James Lennox for introducing me to Aristotle's *Meteorology* IV and also for helping me over the years to appreciate the richness of this text and its connections with other parts and aspects of his scientific corpus. I am also thankful to the International Society for the History of Philosophy of Science—in particular to Rose-Mary Sargent—for helping the three of us to organize a session on *Meteorology* IV as part of an annual meeting of the History of Science Society (San Diego, CA, November 2012). The stimulating comments made by

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mark the boundaries of the study of animals, with which his '(bio)chemistry' is tightly connected.[1] The study of organic and inorganic uniform stuffs and of the processes that cause their constitution and their alterations finds its unifying and defining principles in Aristotle's sustained effort in *Meteorology* IV (henceforth, *Meteor.* IV) to demarcate its object, in his handling of scientific method, and in his search for a distinct and suitable technical terminology, covering kinds (or *genē*) of homoeomers, the processes they undergo, and the material dispositions that differentiate them. In order for Aristotle's science of uniform bodies to acquire a reasonably clear contour and identity and to bolster further scientific research, he had to organize its data in a sufficiently articulate fashion. This clarification and organization of the substance of *Meteor.* IV is achieved to a great extent by appeal to *dunameis*, or dispositions.[2] All four books of the *Meteorology*, along with other scientific treatises, circumscribe the realm of 'for the most part', eluding absolute necessity.[3] In such a world, dispositions are bound to thrive, so to speak, and to exhibit enormous diversity.

Material powers or dispositions (liquefiable, fragile, etc.) play a dominant role in *Meteor.* IV (*a*) in virtue of their central place in the generic division of homoeomers,[4] based on successive differentiation and multiple differentiae, and (*b*) in virtue of their role in revealing otherwise undetectable characteristics of uniform materials (composition and physical structure). While Aristotle often starts with accounts of ingredients and their ratio (e.g., solids that contain a significant amount of water are liquefiable), the natural direction of his investigation is from observations regarding dispositional properties and their manifestation to accounts of composition and microstructure. Such passages tend to be easily syllogizable, a feature that—along with the criteria that shape his method of division—argues, I believe, for the compatibility of *Meteor.* IV with

Andrea Falcon and by members of our audience, including Monte Johnson, after my talk at the HSS meeting inspired many improvements in this article. Thanks are also due to the anonymous referee who made a number of very helpful comments on the previous version of this article.

1. On the many and close connections between these two domains, see also James Lennox's (2014) and Mary Louise Gill's (2014) articles in this issue.

2. I will use 'disposition' interchangeably with 'material power' or 'potential' and 'dispositional property'.

3. The phrase "rather [or: more] disorderly nature"—*phusis ataktotera* (*Meteor.* I.1.338b2)—suggestively reflects the condition of the sublunary world. On the polarity 'always' (unfailingly necessary)–'for the most part', see Sorabji (1981), and see the *Posterior Analytics* 96a8ff. on middle terms and 'for the most part'.

4. In Greek, *homoiomeres* (plural [*ta*] *homoiomerē*)—a homogeneous body whose parts display the same properties as the whole and as each other. 'Homoeomer' will be used here along with synonyms such as 'uniform (or: homogeneous) stuff' (or 'material', 'body', 'compound', 'mixture'). On how homoeomers are formed, see, e.g., *Generation and Corruption* I.10 and II.7 and James Lennox's (2014) illuminating article on the emergence of material complexity.

theoretical texts like the *Posterior Analytics* (henceforth, *APo.*).[5] Thus, my article is also meant to be a contribution to the debate about the extent to which Aristotle's theory of scientific inquiry outlined in the *APo.* and elsewhere was applied systematically in his works on zoology and on uniform bodies in general. One of my main claims is that a careful reading of *Meteor.* IV can lend support to a number of recent studies devoted to Aristotle's biological treatises, studies that emphasize the robust links with Aristotle's programmatic texts dealing with scientific understanding.

With these preliminaries in mind, we should be ready to explore Aristotle's scientific method in *Meteor.* IV, chiefly the ways in which demonstration, causal explanation, and the method of division are deployed there, so that we can properly grasp the nature of his study of homoeomers and gain a more refined understanding of some of the larger philosophical issues looming in the background of *Meteor.* IV.1–11.

Demonstration and Causal Explanation in *Meteor.* IV

In *Meteor.* IV Aristotle carefully sets out the principles that govern the formation and alterations of uniform bodies—organic and inorganic alike. Yet, for all his scientific scruples, his readers might justifiably feel at a loss trying to grasp the precise purpose of the many connections found, especially but not only, in chapters 6–11: connections between dispositional properties of uniform stuffs (liquefiable, liable to increase in density or to evaporate, etc.) and 'chemical' composition (earthy, watery, airy—in various proportions) or microstructural peculiarities—consisting of interlocking parts (see 9.387a11–13), as in the case of viscous stuffs, or having *poroi*, which are pores or invisibly fine channels arranged according to various patterns and pervading solid bodies. These connections are almost always accompanied by references to the effects of the active factors, the hot and the cold, on the passive ones, the moist and the dry (in practice, water and earth), or to mechanical processes, mainly in chapter 9 (e.g., impact, pressure, or stretching). Here is an example from chapter 7: "Potter's clay consists of earth alone [composition], because (*dia . . . to . . .*) it solidi-

5. The relationship between the *APo.* and Aristotle's biological corpus has been a vexed issue. Scholars like G. E. R. Lloyd (1996, esp. 7–37) and Jonathan Barnes are reluctant to accept that Aristotle's scientific treatises follow the *APo.* faithfully. As Barnes (1975/1993, 37) puts it: "Aristotle's scientific treatises are never presented in axiomatic fashion. The prescriptions of the *Posterior Analytics* are not followed in, e.g., the *Meteorology* or the *Parts of Animals*. These treatises do not lay down axioms and then proceed to deduce theorems; rather, they present, and attempt to answer, a connected series of problems." Although Lloyd and Barnes have revised their original positions in some measure, they tend not to stress sufficiently the links that do exist between theory and practice, as Balme, Lennox, and Gotthelf, among others, have done; more on this—later in this article.

fies gradually [dispositional property] when it dries. For water has no ways in [*eisodous*, synonymous with *porous* here; physical structure], through which air alone escaped, nor does fire, since it solidified the clay [effect of heat on that homoeomer]" (7.384b20–22).[6]

Some of the correlations we find in chapters 6–11 are not manifestly causal, but many, indeed most, are. An indication that such connections are not merely meant to organize the considerable amount of data gathered in *Meteor.* IV but aim to help us discern the causes responsible for the emergence,[7] presence, and manifestation of dispositional properties is the number of inferential particles and conjunctions used by Aristotle.[8] The main difficulty for the modern reader may not reside as much in detecting causal connections between categorical properties like structure or composition and dispositions, as in figuring out the direction of the implied inquiry or demonstration: from dispositions to composition (or structure) or the opposite. A few chapters announce that direction explicitly, while others indicate it obliquely; here are some examples.

The central goal of chapter 7 is to offer a division of uniform materials according to the ratio between earth and water in the constitution of uniform stuffs that solidify or liquefy through the agency of hot or cold.[9] The opening lines strike the keynote for the entire chapter, linking a certain material constitution to the corresponding disposition whose manifestation hinges on that constitution as well as on thermic conditions: "Those things that contain more water than earth [composition] are thickened by fire alone [disposition], but those that contain more earth [composition] are solidified [disposition]. Hence (*dio*) both soda and salt are more abundantly earth, and likewise stone and potter's clay" (7.383b18–20). The predominance of earth or of water is signaled here by the fact that a uniform body is prone to solidify or thicken if the right factors (e.g., dry heat) are in place. This explanatory pattern can also be found in other passages in chapter 7: if a particular kind of blood (e.g., that of deer) is not liable to be solidified, it must be because it is watery; "hence [*dio*]," the text goes, "such blood has no fibers. For fibers consist of earth and are solid" (7.384a28). A further sign (*sēmeion*; 7.384a31) supporting this demonstration is that diseased blood does not solidify, as it has not been sufficiently

6. The passages I quote from *Meteor.* IV come from a translation by Mary Louise Gill, James Lennox, and me. The text we used is Fobes's edition (1919/1967).

7. On the emergence of higher-level (material) dispositions and on the notion of *mixis* as presented in *Generation and Corruption*, see Lennox (2014, in this issue).

8. These include *oun*, 'therefore'; *gar*, 'for'; *dio*, 'wherefore'; *dia . . . to . . .* , 'because of', 'on account of', etc.

9. See 7.384a3–4: "Things that are combinations of water and earth are rightly spoken of in accordance with the abundance of one or the other."

concocted and mastered by its nature (*phuseōs*, implying natural heat), so it must be serous and thus aqueous. A similar sort of proof, except for the absence of references to the effects of internal or external heat or cold, is offered toward the end of this chapter: ebony does not float, for (*gar*) other kinds of wood contain a significant amount of air, whereas ebony has a greater proportion of earth (7.384b15–19).

Much like chapter 7, chapter 10 (388a26–27) assumes the task of grasping "which sorts of uniform bodies are forms of earth, which of water, and which are compounds." Later in the same chapter Aristotle concludes: "So if all things are either liquid or solid, and the properties of these are among the affections [*pathesin*, presumably dispositions like solidifiability] we have described, and there is no intermediate, all properties would be mentioned by which we will distinguish whether a thing consists of earth or water or is a compound of more than one, and whether it is constituted by fire or cold or both" (10.389a37). He is thus primarily interested here in determining the composition of the homoeomers by observing their behavior (i.e., the manifestation of their dispositions) under specific thermic conditions.

The goal of chapter 11, however, is to establish which bodies are inherently cold and which hot "on the basis of what has been said" (389a25), that is, on the basis of the just concluded investigation into the composition of uniform bodies in chapter 10. Cold can be regarded, he notes, as matter (*hulēn*) of some sort (389a29), since it is constitutive of earth and water, but most of the discussion in chapter 11 suggests that cold and hot should be considered in this context to be mainly a sort of emerging dispositional property, being due to the effects of the active factors on some underlying material. In short, the direction announced here seems to be from material constitution to dispositional differentiae.

Elsewhere, in the absence of such programmatic or concluding passages, the overall direction of the inquiry is revealed by the topic dominating the discussion. For example, in roughly the second half of chapter 8 and throughout chapter 9 the emphasis is placed squarely on listing, defining, and explaining 18 pairs of dispositional qualities[10]—passive powers (*dunameis*), such as 'breakable' or 'softenable,' and corresponding resistive powers (*adunamiai*), such as 'unbreakable' or 'unsoftenable'. The prevailing goal in chapters 8 and 9, therefore, is to causally explain (at a purely material level) the nature of those dis-

10. Viano suggests (plausibly, I think) that these pairs of differentiae reflect the practical contexts in which they tend to become evident and important: "Les propriétés passives des métaux (solidifiables, fusibles, malléables, ductiles . . .), sont évidemment des propriétés exploitables par la métallurgie et l'orfèvrerie. De même, les propriétés du bois (flexible, fissible, combustible, évaporable en fumée) sont bien connues par le menuisier" (2006, 135–36). Pepe (1982, 26) makes a somewhat similar point.

positions or powers by invoking the composition or structural characteristics of the type of uniform material that exhibits a certain behavior or that is definable in virtue of a specific expected behavior (i.e., disposition or set of dispositions, qualities that can be manifested under the right conditions, such as natural or external heat, impact, etc.). Here is a purely 'chemical' explanation in terms of the ingredients existing potentially in softenable bodies: "Softenable are those solids which are not constituted from water, as ice is, but are more abundantly earth, and neither is all their moisture evaporated, as in the case of soda and salts, nor are they out of proportion, like potter's clay, but are either elastic without admitting water or malleable without consisting of water, and which are softenable by fire, as are iron and horn" (9.385b6–11). The following passage offers a physical or, rather, structural account of fragmentability and breakability: "Those bodies that are solidified in such a way as to have many overlapping pores are fragmentable, for they divide up to this point; those with pores that extend a long way are breakable; and those with both sorts of pores are both" (9.386a15–17). And here is an example of a mixed explanation in chapter 9, involving both composition and physical microstructure: "Absorbent [disposition] are those stuffs that, while consisting of earth ['chemical formula'], have pores that are larger than the portions of water and harder than water, whereas those things are meltable by water that are porous throughout [physical structure]" (9.385b20–22).

The examples surveyed so far suggest that there are two investigative directions at work in the bulk of *Meteor.* IV:

(A) One starts with the observation of (or at least assumptions about) the behavior of organic and inorganic uniform bodies and, by also appealing to the agency of hot and cold and to mechanical factors (pressure, impact, etc., in chap. 9), leads to general accounts of the composition or microstructure of the uniform stuffs under discussion; such general accounts are almost always accompanied by specific examples as well. These demonstrations thus rely on the revelatory role of statements about dispositions as well as on law-like statements focusing on the active factors, cold and (natural and proper or external) heat, or on some mechanical process.[11] The inference is from what is more easily accessible—the expected manifestation of derivative or emergent dispositions—to the 'invisible', that is, to the ratio between the ingredients existing potentially in a homoeomer or the presence of *poroi* arranged according to some pattern or other. We can sum this up as follows:

11. Freudenthal (1995) provides an excellent inquiry, among other things, into the role of natural, innate heat, and its place in Aristotle's theory of matter and of substance.

> If a *genos* of uniform bodies displays—or is expected to display—behavior (*a*) under thermic or mechanical conditions (*b*), it must have the composition or structure (*c*); examples follow.

Here is another illustration, from chapter 10, which is avowedly concerned with determining the constitution—earthy and watery, mostly earthy, watery and airy, earthy and airy, and so on—of the homoeomers: "Those [solids] that have been solidified by heat consist of earth, for instance, potter's clay, cheese, soda [*nitron*, sodium carbonate], salts" (388b11–12). The inference from the specific dispositional properties of particular stuffs to their 'chemical' makeup generally involves three steps, which incidentally make such statements easily syllogizable,[12] although Aristotle never presents his arguments in such formal or technical fashion in his *Meteor.* IV—or in the biological corpus:

> Soda can be solidified by heat.
>
> What can be solidified by heat consists of earth.
>
> . . .
>
> Soda consists of earth (and the same goes for other stuffs that exhibit a similar behavior under similar conditions).

(B) The opposite direction in Aristotle's inquiry into the nature of uniform materials takes us from the composition or microstructure of a certain kind of uniform materials to derivative or emergent dispositions or (passive and resistive) powers that are expected to be manifested under specific conditions like cold, dry heat, and (in chap. 9) stretching, sudden impact, and so on. The purpose of such inferences is evidently not to shed light on what is more obscure or elusive, as in A, but to causally explain the observable characteristics of particular stuffs and of the kinds to which they belong. These explanations can be represented generically as follows:

12. On the syllogizable nature of many passages in Aristotle's scientific treatises, in particular in *Parts of Animals* (*PA*), and on the methodological demands of the *APo.*, see Gotthelf's (2012, 153–214): "Kosman's thesis is that *APo.* should be understood as offering a formal description of proper science, not a requirement that proper science itself be formal. . . . On such a view, which as Kosman has suggested is certainly an intuitively plausible one for Aristotle to take, one would expect *PA* II–IV to have much the logical form it has now. For, whether or not the explanations can in fact be cast into syllogistic form, there is much reason to think that Aristotle himself thought they could be so cast."

> If uniform bodies of a certain kind have composition or structure (*a*), then under thermic or mechanical conditions (*b*) they are expected to display behavior (*c*); examples follow.

In chapter 9, whose main criterion for the division of the homoeomers is their *dunameis*, or dispositions, and which is intended to define and explain those material dispositions, we read that "some things are combustible, others incombustible—for instance, wood is combustible, as are wool and bone, whereas stone and ice are incombustible. Things are combustible that have pores receptive of fire and have moisture in their longitudinal pores that is weaker than fire" (9.387a17–19). Such statements too can be reformulated in syllogistic fashion, as the underlying reasoning from composition and structure to dispositions seems to involve three stages:

> Wood has longitudinal pores receptive of fire and containing moisture that can be overcome by fire.
>
> What has longitudinal pores receptive of fire and containing moisture that can be overcome by fire is combustible.
>
> . . .
>
> Wood is combustible (and so are other uniform bodies that have a similar composition and physical structure).

If we compare this syllogism with the previous one (under A), we can see that the middles, the elements common to the premises (here: what has longitudinal pores, etc.; in the previous example: being solidifiable by heat), play decidedly different roles. As I have already suggested, the role of the middle in an inference meant to help us identify the composition or microstructure of a body (by resort to its dispositions and to law-like statements) is a certain dispositional property and is revelatory in the sense that it is meant to help us find or reveal the causes of the dispositional qualities of that body. The expected behavior of a homoeomer under certain conditions is certainly not the cause of the constitution of that homoeomer—quite the opposite is the case—but it can presumably point to its causes, to what is otherwise imperceptible (*poroi*) or hard to detect (the ratio between ingredients, esp. earth and water).

However, the middle (represented by composition or structure) of an inference that concludes with a statement about what disposition characterizes some uniform stuff provides the cause, in the strict and strong sense of the word, for that disposition. Wood, for example, would not be combustible, according to Aristotle, if it did not have longitudinal pores containing relatively little moisture that can be overcome by fire; such features causally explain the presence and, along with other factors like exposure to heat, also explain the manifestation of dispositions such as the combustibility of wood. While in the course of scientific investigation, inferences starting with dispositions would normally precede causal explanations, A-type and B-type inferences alternate in the text of *Meteor.* IV, with the A-type inferences being the protagonists in chapters 7 and 10 and occasionally showing up elsewhere.

The theoretical implications of this distinction will become apparent if we consider a couple of celebrated passages in a treatise that outlines Aristotle's theory of scientific inquiry, his *APo*. In chapter 13 of book I Aristotle distinguishes between understanding 'the fact' (*hoti*) and understanding 'the reason why' (*dioti*), within the same science (78a23–78b34) or in different sciences (i.e., 'the fact' being the object of a science; 'the reason why', the object of another science, as is the case with optics and geometry; 78b35–79a16). In order to elucidate the first case—sciences that deal both with the fact and with the reason why—Aristotle offers a number of examples. The first example goes somewhat like this: from the fact that planets do not twinkle, one can infer that planets are near (i.e., closer than the fixed stars), provided one also posits that what does not twinkle is near.

> Let C be the planets, B not twinkling, A being near. It is true to say B of C: the planets do not twinkle. And also to say A of B: what does not twinkle is near. (Let this be assumed through induction or through perception.) Thus it is necessary that A holds of C, and it has been demonstrated that the planets are near. Now this deduction gives not the reason why [*dioti*] but the fact [*hoti*]: it is not because the planets do not twinkle that they are near—rather, because they are near they do not twinkle. (I.13.78a30–78b3; trans. Barnes 1975/1993)

In this type of demonstration, then, the middle (not twinkling) is 'the fact', intended to point to its own cause—if, again, we also hold that what does not twinkle is near. Such inferences reflect understanding (*epistasthai*) in a weak sense. This example is reminiscent of those demonstrations in *Meteor.* IV in which the middle is a disposition (e.g., meltable, flexible) of some homoeomer, and the conclusion states the composition or structure of that homoeomer. The emergent material disposition does not explain, say, the composition, but it does contribute presumably to our grasping that composition. Conversely, to quote from the same chapter 13 in *APo*. I, "It is also possible to prove the latter through the former, and then the demonstration will give the reason why (*dioti*). For example, let C be the planets, B being near, A not twinkling. B holds of C and A of B: hence A holds of C. The deduction gives the reason why, since the primitive explanation has been assumed" (I.13.78a39–78b3; trans. Barnes 1975/1993). The middle here, common to the premises 'The planets are near' and 'What is near does not twinkle', is the cause for what is mentioned in the conclusion, 'the planets do not twinkle'. This, in other words, is an instance of a causal explanation that can secure understanding in the robust sense of the word. Similar examples can be found in the 'chemical treatise'; as we have seen, in *Meteor.* IV (e.g., in chaps. 9 and 11) there is no shortage of inferences in which the middle refers to the composition or structure of a uniform stuff and the conclusion states one of its dispositional properties, whose nature is caused by—and is explainable through—the composition or structure of that stuff.

Although *Meteor.* IV.1–11 does not display a formulaic language studded with symbols and neatly articulated syllogisms, it seems to reflect important aspects of *APo.* I.13. In the language of *APo.*, the scientific effort to understand the nature of organic and inorganic materials in a largely nonteleological context captures both 'the fact' (dispositional accounts of the homoeomers) and 'the reason why' (the underlying causes for the characteristic behavior of various kinds of homoeomers). Now, Aristotle's study of animals, too, reflects the case in which a science deals both with 'the fact' or the facts, including the presentation and organization of data (this task being assumed primarily by his *Historia Animalium*; hereafter, *HA*) and with providing causal explanations or 'the reason why' for those data, that is, for why a certain kind of animal has the specific set of attributes that it has, with respect to anatomy, mode of reproduction, and so on—this task being assumed by *Parts of Animals* (*PA*) and *Generation of Animals* (*GA*), among other works.[13]

The difference between Aristotle's biological corpus and his study of homoeomers is that the latter deals with both 'the fact' (*to hoti*) and 'the reason why' (*to dioti*) in one and the same work, his *Meteor.* IV, although the emphasis on *to hoti* or *to dioti* alternates from one chapter to another. Besides, unlike in the zoological works, in *Meteor.* IV.1–11 'the reason why' is not spelled out in teleological terms, pertaining to the functions fulfilled by uniform parts in a living organism. Thus, 'the fact' (potentials like liquefiability) and 'the reason why' (e.g., the ratio between earth and water in a uniform mixture that is liquefiable) are both situated at a material level and can grant only a partial in-

13. On this see Lennox (2014), esp. the sections "The Relationship of *Meteor.* IV, *GA* and *PA*" and "Developmental Thermodynamics."

sight into the nature of the homoeomers; a more thorough understanding also needs to rely on the discussion about functions—the other *dioti*, crucial to a more comprehensive scrutiny of the organic homoeomers that are to be defined eventually not just in virtue of their material dispositions and constitutions but also in virtue of their specific roles in the organisms of which they are parts. *Meteor.* IV.12, which is properly examined by Mary Louise Gill (2014, in this issue; see also Gill 1997), emphasizes the complementarity of material and formal explanations and the relation between Aristotle's study of uniform materials in general and his (final) causal explanations as deployed in *PA* and *GA*.[14] Here are the final lines of chapter 12: "For we know in each case why and what it is in the following way: if we get hold of either the matter or the definable form, and most when we get hold of both causes of the generation and destruction, and also whence the source of the motion. When these things have been clarified, we must likewise study the nonuniform bodies, and finally the things constituted from these, for instance, human being, plant, and other such things" (12.390b17–22). In short, *Meteor.* IV appears to have a hybrid status: it is thematically autonomous, covering 'the fact' and 'the reason why' insofar as both organic and inorganic homogeneous stuffs are considered from a generally nonteleological angle; however, it affords only a partial account of organic uniform stuffs if we aim to also better understand their natures in their proper biological context (the latter contributing the functional 'reason why', so to speak).

I will return to the relation between *Meteor.* IV and the biological works in the conclusion of this article. For now, an additional clarification may be opportune here. Just as the two passages I quoted from *APo.* I.13 include general statements that resemble what we would call laws of nature ("what does not twinkle is near"; "what is near does not twinkle"), the arguments formulated in *Meteor.* IV virtually always contain law-like premises: compounds of earth and water are solidified both by fire and by cold, what has longitudinal pores receptive of fire is combustible, compounds that contain more water than earth are only increased in density by fire, what has pores that extend a long way is breakable, and so on.[15] The consistent use of such premises suggests that our sole awareness of a thing's dispositions cannot get us to its composition or its microstructure, but if you know that some material (e.g., silver) is likely to melt when exposed to heat *and* if you also hypothesize that what melts contains

14. See, e.g., the end of *PA* II.5: "We have stated, regarding blood, serum, and soft and hard fat, both what each of them is (*ti*), and owing to what causes (*dia ti*) each of them is" (trans. Lennox 2001a). This passage sounds remarkably like the end of *Meteor.* IV.12.390b15–16: "Since we know the kind to which each of the uniform bodies belongs, we must grasp what each is individually, for instance, what blood is (*lēpteon kath' hekaston ti estin, hoion ti haima*), or flesh or semen, and each of the others."

15. On law-like formulations in *Meteor.* IV, see also Lennox (2014).

water, then you can conclude that it (e.g., silver) contains water, which perhaps predominates in its composition.

By and large, Aristotle does not find it necessary to explain to his readers how he reached such law-like claims in *Meteor.* IV. He famously notes (*Physics* II.1) that, in natural philosophy, it would be superfluous to demonstrate that there is such a thing as nature. But, whereas this may indeed be taken to be self-evident, it is far less obvious that what is meltable (e.g., silver) contains water. What are such hypotheses based on? Sometimes Aristotle appears to tacitly ground his 'laws' on analogies (e.g., between an element and a state of aggregation: water and liquid, earth and solid), a type of 'confusion' that is quite pervasive in *Meteor.* IV. Similarly, he posits the existence of *poroi*, on the basis of an analogy with various bodies like sponges (386a30; although possible influences from other authors are not to be discounted).[16] However, he does not explain in *Meteor.* IV how *poroi* come about in various bodies, what determines the formation of distinct types of *poroi*, and so on.[17] *Poroi* play an important explanatory role not only in elucidating how a liquid can penetrate and alter a solid body but also in Aristotle's accounts of 'physical' dispositional differentiae such as fragility (386a9–17) and fissility (386b26–387a3).

Analogical inference is also what enables Aristotle to contend that the tendency of olive oil to float on water is due to its high content of air (after all, air naturally moves upward; 7.384a3–8) and that amber is formed by solidification and contains earth: "amber too likely belongs to this kind [i.e., solids composed of earth], and is solidified—animals are at any rate manifestly trapped in it—and the heat driven out by river-water, as in the case of boiled honey, when it is dropped into water, evaporates the moisture" (10.388b22–

16. I have not found any occurrence of the term *poros* in the *Timaeus*, although Plato is certainly interested in the physical inner structure of various bodies and substances, this allowing him to explain phenomena such as increase and decrease in density; certain interstices also account for the relative lightness, e.g., of bronze (59c). But, despite terminological differences (to *poros*, Plato prefers *dialeimmata*, 59c2; *diakenōn*, 60e4; *euruchōrias*, 60e5; *diexodon*, 60e8; *eisodos*, 61a2; *diakena*, 61a5, 61b1, 61b4), similarities with Aristotle's account are startling. Empedocles too could conceivably have been one of his sources of inspiration, considerable differences notwithstanding.

17. As I mentioned before, *poroi* can display several characteristics; again, Aristotle does not deem it necessary to offer a cogent demonstration of this fact. We learn from Aristotle that *poroi* can be distributed in the mass of a solid body in different ways—evenly, by fascicles, etc. (e.g., at 385b25—in earth the pores 'alternate'; cf. 386a16, 386b2ff.); they can be arranged longitudinally; they can be 'hard' (385b21: [*porous*] *sklēroterous tou hudatos*, literally, "[pores] harder than water"); or they can have different diameters: "pores that are larger than the portions of water" (*porous meizous tōn tou hudatos ogkōn*; 9.385b20–21; cf. *Generation and Corruption* I.9.326b30ff.). On the question whether the causal explanations based on the existence of *poroi* are reconcilable with Aristotle's other tenets and with his critique of Empedocles, see Baffioni (1981), 35, and Pepe (2002), 31–33, among others. The consensus among contemporary scholars is that the explanations based on *poroi* (mostly in chap. 9) cannot prove that *Meteor.* IV or part of it is spurious.

24).[18] Experiments too, rudimentary though they may be, can support some of Aristotle's statements about the composition of uniform stuffs; in chapter 7 (384a3–8) he tells us that new wine is not just a form of water but a compound of water and earth, since it is solidifiable when boiled; that it dries as a result of the evaporation of water is shown (literally, "the sign is that," *sēmeion d'hoti*) by the fact that if we collect the steam when the wine is brought to a boil, it will condense into water.

I cannot delve here into a more detailed treatment of law-like premises and of how Aristotle is likely to have produced such claims, but I should conclude my brief comments on this point with a word of caution. When mustering such principles, Aristotle scarcely betrays any hesitation. This attitude is, I believe, worth almost as much attention as the various aspects of his scientific method. I would tentatively suggest, however, that the absence of any conspicuous and confessed hesitation on Aristotle's part should not necessarily be taken to indicate that he thought himself in full command of the 'truth', for example, regarding the composition or the texture of a certain uniform body. A passage in the first book of *Meteorology* may be pertinent here. Right before tackling the nature of comets (I.7.344a5ff.), Aristotle admits that he has to settle for less than sheer certainty. He considers that his account about what is imperceptible (*peri tōn aphanōn*) is reasonable (*kata ton logon*) enough if his explanation is at least possible (*eis to dunaton*).[19] This passage could have very well prefaced *Meteor.* IV as well.

In my analysis of demonstration and causal explanation, and of the common points between their application in *Meteor.* IV and their treatment in *APo.*, I alluded repeatedly to the importance of the method of division as used in this treatise. We should, therefore, take a closer look now at Aristotle's handling of division, or *diairesis*.

Division

The concluding chapter of *Meteor.* IV, chapter 12, takes stock of the first 11 chapters while also connecting this study of homogeneous materials, in particular some of the organic ones, with the project that forms the next stage in Aristotle's scientific program: the study of animals (see *Meteor.* I.1). He seems to be thinking of those sections of his biological corpus, such as *PA* II.4–9 and

18. For more on the peculiar properties of oil in the context of Aristotle's works, see Freudenthal (1995), 175ff.

19. For a recent study of the limits of Aristotle's empirical standard for the assessment of scientific theories, and for helpful comments on how Aristotle deals with the "paucity of appropriate perceptual data," see Bolton (2009), 51–82.

much of *GA*, where the nature of uniform parts like milk, blood, semen, and marrow is considered both from the angle of their material constituents and from that of the functions that essentially define them. As Aristotle puts it at the beginning of chapter 12, "Since we have determined these things, let us state individually what flesh, bone, and each of the other uniform bodies are. For we get hold of the things from which the nature of the uniform stuffs is constituted, their kinds (*ta genē*), and to what kind each belongs (*tinos hekaston genous*), through their generation. For from the elements are constituted the uniform bodies, and from these as matter are constituted whole works of nature" (12.389b23–28). The end of chapter 12 resumes this idea in symmetrical fashion: "So if we get hold of the kind to which each of the uniform bodies belongs (*tinos genous hekaston*), we must grasp what each is individually, for instance, what blood is, or flesh or semen, and each of the others" (12.390b14–16). The mention of generation (*genesis*) and of the elements from which the uniform bodies are formed is a clear reference to the very first chapter of *Meteor*. IV but also, I take it, to the chapters (e.g., 7 and 10) in which Aristotle sets himself the task of establishing the original ingredients of the homoeomers and the rough ratio (*logos*) between them. Note that he states in the same breath, at the beginning of *Meteor*. IV.12, that if we understand how those stuffs are generated, we should also be in a position to provide a generic division into kinds, presumably based on their composition: earthy stuffs, watery ones, mixtures in which earth or air prevails, and so on. Besides, as we have seen, he also carves the domain of the homoeomers into kinds delimited by their material potentials or *dunameis* (solidifiable, breakable, combustible, etc.). Two observations should be made at this point.

First, the two types of inferences I discussed in the previous section, I believe, correspond to and indeed necessitate a division carried out along two sets of differentiae:[20] (*a*) material dispositions like 'meltable' and (*b*) compositional and structural features like 'being mostly earthy' or 'having alternat-

20. The Greek term for division is *diairesis*, frequently used in the biological works. It does not occur, however, in *Meteor*. IV (the verb *diairein* is used 11 times there but with concrete meanings like 'to split' or 'to disperse'). One may be under the impression that *diairesis* aims in the biological works at a classification of animals, comparable with modern zoological classifications. Balme was a staunch critic of such analogies. In several of his papers he pointed out convincingly that Aristotle's divisions were meant not to classify but to define, or, as Aristotle would say, to "hunt" for the definiendum, to discover exactly what an animal species is. In Balme's words, "[Aristotle] does not carry the framework of division across the board as in a classification, nor does he create a terminology of orders, families, etc., as Linnaeus did to establish such a framework. . . . Modern taxonomists have been mistaken in seeking a classificatory system here. For in biology Aristotle uses only two taxonomic concepts, the *genos* and the forms of a *genos*, and all attempts to find regular intermediate classes have notoriously failed" (1987, 72). In *Meteor*. IV the terms *diaphora* ('difference', 'differentia'), *dunamis* ('power', 'disposition'), *pathos*, and *pathēma* ('affection', 'quality') are sometimes used interchangeably: 8.385a5, 8.385a12, 8.385a20,

ing pores'. The emphasis placed on one set of criteria or the other seems to differ according to whether a chapter is devoted primarily to defining and explaining dispositional differentiae (as, e.g., in chap. 9) or to shedding light on the constitution of uniform stuffs (as, e.g., in chap. 10). This difference in emphasis, however, often becomes rather blurred; in chapters 6 and 7, for instance, the division according to the ratio between ingredients (mainly water and earth) is not obviously more prominent than the one based on, say, distinctions between solidifiability by heat or by cold, even if the declared goal of chapter 7 is to determine the amount of water and earth in the homoeomers (7.384a3).

Second, demonstration and the method of division are interdependent in *Meteor.* IV; furthermore, they are achieved simultaneously, in the course of the same chapters. When Aristotle declares that "of those materials that are thickened by fire without evaporating, some consist of earth, whereas others are compounds of water and air—honey consists of earth, whereas olive oil is a compound of air" (7.364a14–16), he is attempting to demonstrate that homoeomers that display a particular behavior under the agency of heat have a particular 'chemical' composition, and he is indicating that honey, to take this example, belongs to the group of stuffs whose thickness is increased by dry heat *as well as* to a group that is describable in virtue of a certain content of earth.

A quick glance at Aristotle's *HA* will throw this second observation into sharper relief. In chapter 6 of the first book (491a6ff.), Aristotle sets forth the central goal of this treatise, which is to mark out the differentiae (*diaphoras*) and attributes (*sumbebēkota*) of all animals; this inquiry into the distinctive characteristics of animals will then enable him to discover the causes (*aitias*) that explain why a kind of animal has the attributes it has. This second task, the discovery of causes, is fulfilled not within *HA* but in works like *PA* II–IV and in *GA*. This presents a partial contrast with *Meteor.* IV. It is true that, in order to properly understand the nature of animal tissues, one has to read *PA* II. 4–9 and sections of *GA* (that draw lavishly on *Meteor.* IV), in addition to *Meteor.* IV itself.[21] After all, *PA* and *GA* are centered on teleological explanations that point to the essential natures of such uniform parts. In other words,

10.388a10; see also the frequent use of the verb 'to differ' (*diapherein*) in the first half of chap. 8, among other passages.

21. Here are just a few passages in *GA* that seem to echo *Meteor.* IV: *GA* II.1.734b25ff. (on heat and cold as being capable of producing uniform parts with their dispositional differentiae but not instrumental parts, etc.); II.6.743a4ff., 743a18ff. (on the agency of cooling and heat); 743a36ff. (same topic, connected with the notion that both material necessity and final causation should be assumed in the generation of organic homoeomers); III.2.753a25ff. (on the earthy nature of yolk).

PA and *GA* provide 'the reason why'; blood, for example, is what it is not just because it is a liquid whose content of earth (fibers, or *ines*) varies from one species to another and can coagulate, and so on, but also and principally because it is the nourishment for all the parts of the body and is also responsible to some extent for temperamental features and for acuity of perception. Still, as we have seen, *Meteor.* IV deals in a sense both with 'the fact' (the collection and organization—which entails division—of data, based there on the distinctive properties of the homoeomers) and with one aspect of 'the reason why'—the underlying causes of the dispositional properties (e.g., the meltability of certain metals is caused in part by their content of water). Unlike in *HA*, then, in *Meteor.* IV a discussion of 'the fact' is inextricably bound up with a search for 'the reason why' (considered only at a material level), and both are dealt with within the same work, the formal or teleological accounts being announced in *Meteor.* IV.12 and supplied in *PA* and *GA*.

This being said, there is much that *Meteor.* IV shares with *HA*, as both are designed to prepare the terrain for functional explanations like those offered in *PA* and *GA*. Thus, one of the main achievements of *Meteor.* IV is to provide criteria for a reliable and clearly articulated division of the various homogeneous bodies into overlapping kinds,[22] or *genē*—an enterprise that turns out to be especially useful in *PA* II.4–9 and various portions of *GA* II and V. It appears, therefore, that a proper understanding of Aristotle's method of division in *Meteor.* IV could help us to explain more precisely the purpose of this book on its own terms and also in the larger context of Aristotle's scientific agenda.

Aristotle is likely to frustrate a modern reader who expects a classification in the modern sense of the word; he does not classify homoeomerous bodies, for instance, into natural and artificial (alloys, etc.), the natural ones into inorganic and organic, the inorganic ones into types of stones and metals, the organic ones into vegetal and animal tissues, and so on. And in *Meteor.* IV he is certainly not interested in offering individual accounts of homoeomers; virtually every homogeneous material, from wood to olive oil, is discussed at sev-

22. The technical terms (chiefly the use of 'kind', or *genos*, and 'form'/'species', or *eidos*) pertaining to division in *Meteor.* IV are the ones Aristotle also uses in his biological writings. *Genos* (pl. *genē*) occurs at 388b22; cf. 390b15; *eidos* (pl. *eidē*), at 379b10, 17, 381b4, 23, 382b11, 13, 383b14, 388a26; 'the more and the less'/'by degree' (*mallon . . . hētton*), at 382a17. *Genē* are analyzable into *eidē*; the *eidē* themselves can be regarded as *genē* in respect to the *eidē* into which they are further divisible. It is worth mentioning that many of these *genē*/*eidē* do not have proper names, and, therefore, Aristotle uses a sort of improvised nomenclature: 'the earthy ones', 'the easily liquefiables', etc.—a linguistic situation comparable with that in his biological writings: 'the soft-shelled ones', 'the live-bearing four-footed animals', etc. Compare Düring on the list of 18 pairs of dispositional differentiae in chap. 8 (discussed in chaps. 8 and 9): "It is but natural that a writing of this kind requires a number of new words, some of which were certainly fabricated *ad hoc*. This is patent to everyone in the case of the words with a *negativum*" (1944/1980, 21).

eral points in this book, in contexts that focus on material capacities or *dunameis*, on the ratio between the original ingredients, or on the types of *poroi* present in solids. In his biological works, too, Aristotle ponders what may be the best way to structure his study; in his treatise on what we would call today philosophy of biology, *PA* I, he wonders (1.639a16ff.) whether one should consider the nature of each animal separately (*kath'hekaston*) or whether it would be more profitable to lay down the animals' common attributes (*ta koinēi sumbebēkota*) that are due to some common factor (*kata ti koinon*). It is the latter approach that he takes up in his *HA*—and the same goes for his *Meteor.* IV, where he speaks of 'earthy' materials or 'the earthy ones', of 'the predominantly watery ones', and of the 'flexible ones', 'the ones giving off fumes', stuffs that have many overlapping pores, and so on. The potentially disorienting slew of such kinds in *Meteor.* IV amounts in fact to a careful division of uniform materials with respect to the processes they are liable to undergo (and, so, with respect to their dispositional properties), for example, solidifying or catching fire, as well as by employing their composition and microstructure as causal differentiae.

Divisions are meant to organize the facts (see *APo.* II.13), in order to identify causal differentiae and to grasp 'problems'.[23] As Lennox puts it, with regard to Aristotle's method of *diairesis* in his biological works (2001b, 35–36 n. 26), "Division is a way of organizing information for the sake of explanation/definition, not a method of discovering information."[24] Aristotle lays the

23. On grasping problems through divisions, see *APo.* II.14: "In order to get to grips with problems, you should make excerpts from the anatomies and the divisions. Do this by supposing the kind common to all the items and excerpting—if, e.g., it is animals which are being studied—whatever holds of every animal. Having done this, next excerpt whatever follows every instance of the first of the remaining terms (if, e.g., it is a bird, whatever follows every bird)" (98a1–6; trans. Barnes 1975/1993).

24. Producing increasingly complex and enlightening definitions allows us, according to Aristotle, to proceed from merely fumbling around (starting an inquiry with a rudimentary degree of understanding or amount of knowledge; *APo.* II.10.93b32–36) to grasping what a thing really is (i.e., formulating a causal account and thus acquiring understanding; see *APo.* 93a28 and 93a17–21). When it comes to uniform stuffs and to fully defining their nature, *Meteor.* IV may seem at first to be just a source of nominal definitions (which indicate for us the phenomenon that should be investigated; a real definition points us to the cause of the thing that we are attempting to define; see *APo.* II.7). Compare a *Meteor.* IV.1–11–like definition of flesh as 'a uniform stuff that is mostly earthy, is flexible etc.' with a functional account such as 'flesh is a uniform part that makes tactile perception and movement possible'. Yet, at least with respect to emergent material dispositions, *Meteor.* IV is meant to probe quite deeply and to seek more than just nominal definitions of *dunameis* by revealing the underlying causes—chemical composition and microstructure—and the conditions that lead both to the emergence and to the actualization of those *dunameis*; chaps. 8–9 of *Meteor.* IV, e.g., are replete with such rich definitions. As for uniform stuffs themselves, in order to get more complete accounts of them, we will have to look them up in the biological treatises, where they are defined by appeal to functions, or *erga*. On the relation between division and definition, see also *APo.* II.13, e.g., 97b11–16, and *Metaphysics* Z 12.

theoretical foundation for division or *diairesis* in several texts, including *APo*. II. 13–14 and *PA* I. In *PA* I, more than anywhere else, Aristotle is out to demolish the method of dichotomy he attributes to Plato and offers a fundamentally new technique.[25] My main suggestion in the next few pages is that *Meteor*. IV largely follows the theoretical precepts conveyed in *APo*. II and *PA* I. Here is a very succinct overview of the principles governing the method of division, as put to work in the fourth book of *Meteorology*.

Successive Differentiation

In the *Statesman*, Plato divides animals into aquatic and terrestrial, terrestrial ones into winged and what walks, and so on (264aff.).[26] Another example of dichotomy is offered by Aristotle at *PA* I.3.643b19–25: animals are divided there into 'winged' and 'wingless', 'winged' animals being grouped into 'tame' and 'wild' or into 'pale' and 'dark'. This arbitrary way of dividing cannot guarantee that one will end up with a complete set of defining characteristics of a certain kind of animal. As a remedy, Aristotle introduced a requirement for successive differentiation, meant to ensure that the final differentia will entail its antecedents (cf. *APo*. II.14.98a8–10). Footed animals, for example, can be divided into two-footed and many-footed, the latter into four-footed, and so on. Being four-footed, of course, is a sort of footedness; if footed animals were divided into gregarious and solitary, it would be evident that such attributes could not be derived from 'footed', except accidentally. Here is a relevant ample from *Meteor*. IV. In chapters 5–7 there is an overarching contrast between solidification and liquefaction; both processes (and corresponding material dispositions—solidifiable, liquefiable) are distinguished into subtypes, according to whether they are caused by heating or by cooling. An additional criterion for division is whether solidification and liquefaction occur in watery liquids or in compounds of water and earth (the latter being further divisible according to which—water or earth—predominates).

Multiple Differentiae

Division, Aristotle recommends, must be done by multiple differentiae. If footed is divided into two-footed and many-footed, and this category into four-

25. Its main features are discussed in a classic article by Balme titled "Aristotle's Use of Division and Differentiae" (1987, 69–89) and also in a study by Lennox titled "Divide and Explain: The *Posterior Analytics* in Practice" (2001b, 7–38); this section of my article bears their profound mark.

26. For a recent and very helpful discussion of that section of the *Statesman*, see Gill (2012), esp. 179–85.

footed and six-footed, and so on, this is a perfectly reasonable and legitimate division; it is, however, glaringly insufficient. To say that humans are two-footed and to say that elephants are four-footed scarcely gets us to the essence of what a human is or at what an elephant is. The solution is to operate with several divisions simultaneously. To get a firm understanding of the nature (in a nonteleological context) of an animal in *HA*, you need to track down its features in sections concerned with uniform and with instrumental parts, with modes of reproduction, with diet, and so on. As I mentioned before, in *Meteor.* IV, Aristotle divides uniform bodies according to two major sets of criteria: (*a*) the various dispositional properties possessed by those uniform stuffs and (*b*) their composition (earthy and watery stuffs, etc.) and physical characteristics (such as the presence of tiny pores or channels in a mass of, e.g., clay or salt). In the end, if you want to know what the material nature of, say, wood is, you have to consider all of Aristotle's divisions and lists of dispositional properties and come up with a jigsaw puzzle of sorts: wood is a uniform mixture that contains mostly earth and air in a particular ratio, has *poroi* arranged longitudinally, is combustible, is fissile, and so on. One and the same composition or physical structure may correspond to several of the 18, or rather 36, dispositions listed in chapters 8 and 9, since the same material, say, wood, can be at the same time fissile (*schiston*), combustible (*kauston*), unmeltable (*atēkton*), capable of giving off fumes (*thumiaton*), etc. Conversely, the same disposition (e.g., meltability) can indeed be found in homoeomerous stuffs with distinct compositions (different ratios between dry and moist or earth and water), but the disposition will be situated at different points on the unmeltable–very-easily-meltable continuum, for meltable stuffs as diverse as wax and silver.

This method of division is theoretically conducive to the formulation of definitions, but they are likely to remain incomplete definitions in that context. Such divisions can help us to outline the material nature of salt, iron, or suet, but, at least when it comes to organic uniform bodies (root, bark, suet, blood, bone, etc.), *Meteor.* IV will not exactly reveal their essences, as, again, a full account of their natures would require us to consider them in the context of whole organisms and, so, to place them in a teleological context and to specify their respective functions (as suggested by chap. 12 of *Meteor.* IV and as illustrated by much of *PA* II).

Division by Opposite Differentiae

In his summary and interpretation of *PA* I.2–3, Balme notes that "Aristotle criticizes the kind of empirical division that would be made if in defining a colorless fish we were to divide animals into swimming and colored. This would produce a cross-division by changing the *fundamentum divisionis*, since there may be animals that both swim and are colored. . . . At the end we could not guarantee that the final differentia is exclusive to our object" (1987, 75). We need, therefore, to divide only by opposites. In *Meteor.* IV Aristotle is consistently keen on dividing by opposites, at a dispositional level or at the level of material constitution: solidifiable stuffs can be divided into those that are solidified by cold and those that are solidified by heat; compounds can be divided into those in which earth predominates and compounds in which water predominates. Although it is preferable to divide by positive opposites (A and B; see Balme 1987, 76) rather than by negative differentiae (A and non-A), Aristotle does not shun divisions where the presence of some *dunamis* is seemingly contrasted with its absence. One of the most obvious examples is his list of dispositions in chapters 8 and 9 and, implicitly, his division of homoeomers into groups characterized by 18 pairs of dispositional properties (*dunameis* and *adunamiai*): capable or incapable of solidification, meltable or unmeltable, softenable by heat or unsoftenable by heat, and so on. Nonetheless, *adunamiai* like 'unmeltable' or 'unsoftenable by heat' are not mere instances of privation or *sterēsis* but can be regarded as 'positive' states or properties, insofar as they are resistive powers—in these cases, the power or *dunamis* to resist some agency of heat or pressure, impact, etc.

'The More and the Less'

Let me conclude this succinct enumeration of points of convergence between the use of the division, or *diairesis*, in *Meteor.* IV and Aristotle's theoretical precepts regarding this method, by calling attention to divisions made in terms of degrees.[27] A comparison between significantly different kinds of animals can be facilitated by analogy (lungs–gills, feathers–scales, etc.); however, when marking distinctions between animals pertaining to different forms that belong within the same kind, Aristotle relies on degrees or 'the more and the less' (e.g., species of birds can be compared and contrasted by pointing out that one has a larger beak than some other species; see *PA* I.4.644b7–14). Aristotle's 'chemistry' is not quantitative in any rigorous way, but he does attempt to differentiate between various ratios in the material composition of stuffs belonging to the same *genos*; in chapter 6 of *Meteor.* IV, for instance, Aristotle distinguishes compounds of earth and water between those in which earth predominates and those in which water is the dominant ingredient; furthermore,

27. For more details, see chap. 7 in Lennox (2001b), 160–81.

among the former (in which earth is prevailing), one can discern various degrees in the preponderance of earth.[28] Degrees in the predominance of some ingredient appear to correspond (along with differences in the configuration of the pores, or *poroi*) to different positions of *dunameis* along continua such as absorbent–nonabsorbent or combustible–incombustible.

The division of homoeomers in *Meteor.* IV is certainly not exhaustive. For instance, almost nothing is said in *Meteor.* IV about active derivative dispositions.[29] Yet, while Aristotle's overall purpose in this book is not to provide a complete and detailed classification of homogeneous compounds, he does succeed in producing a set of generic divisions—made in a spirit remarkably reminiscent of *PA* I—that are meant both to organize a vast amount of information and to bolster further investigation into the nature of organic uniform stuffs. These materials will become the object of renewed scrutiny in the biological works, where the study of various tissues (considered separately, *kath'hekaston*) will include a systematic search for their defining functions.

Notes on *Endoxa* and on Teleology in *Meteor.* IV.1–11

Before I conclude, let me add two notes on what readers familiar with some of Aristotle's other scientific works might expect to find in *Meteor.* IV but will not: a systematic discussion and criticism of *endoxa* and a sustained appeal to final causation. The review and evaluation of reputable opinions, or *endoxa*, is a staple of Aristotle's method and rhetoric of science, yet, in *Meteor.* IV, such *endoxa* are all but absent. Aristotle defines this concept at the beginning of his *Topics* (I.1.100a30–b23), where he is concerned with the distinction between several types of reasoning (*sullogismos*). Dialectical reasoning takes its starting point from *endoxa*, opinions that are embraced by everyone or by the majority or by the wise (either by all or the majority or the most famous and reputable—*malista gnōrimois kai endoxois*—among the wise). In most of his scientific works, Aristotle readily engages established theories formulated by other thinkers and defines his own views against this background. He seems, however, in no dialectical mood in *Meteor.* IV, which is decidedly atypical for him and is surprising especially if one compares *Meteor.* IV with other treatises, including

28. See, e.g., *pleon echontōn gēs* ("containing more earth") at 383a27.

29. A few exceptions can be found at 8.385a2–4 and 10.388a12, where Aristotle lists perceptible properties like white and sweet; they are contrasted in chap. 8 with passive (*pathētika*) or 'more proper' qualities (*oikeioterois*; cf. *Physics* VII.246b10, where *oikeia pathē* are said to be responsible for the natural generation and destruction of things).

Meteor. I–III, where he invokes and takes his predecessors to task with rather remarkable frequency.[30]

In the fourth book of the *Meteorology* Aristotle is content to only quote Empedocles twice—to express his agreement with him and to avail himself of the suggestiveness of memorable dicta.[31] Occasionally we find an impersonal "it is said" or "they say" (*legetai*); for instance, at 382b9 we read that "cold is said to burn," but, again, this is not meant to suggest a difference of position from Aristotle's but to muster what he takes to be a common perception of the effects of cold in support of his own statement that cold is primarily an active factor. At most, he appears sometimes to complete or clarify a common opinion or an earlier account (e.g., in chap. 11, at 389b13ff., a passage where he seeks to provide a clarification, rather than a rebuttal, about what qualifies as hot or cold). The reason for this consistent and unusual lack of emphasis on *endoxa* in *Meteor.* IV may be the sheer novelty of Aristotle's comprehensive approach.[32] Or it may be that some 'reputable opinions' and some popular views could have been tacitly incorporated into the substance of this book, alongside Aristotle's own observations, but any solution to this puzzle is likely to remain a matter of speculation, and so I prefer to end my note about this peculiar absence in aporetic fashion.

Less mysterious but equally striking is the scarcity of references to final causation throughout most of *Meteor.* IV, with the notable exception of the last chapter, chapter 12, whose treatment of final causes is intrinsically and programmatically interesting. One of the problems raised in chapter 12 is whether the agency of hot and cold is sufficient for the formation of organic uniform stuffs like flesh, a problem discussed in detail and elucidated in Gill (2014).

30. That Aristotle's review and critique of his predecessors' theories is a central aspect of his method in books I–III is stressed by Freeland (1990, 317): "In his preliminary studies of the *endoxa*, I have argued, Aristotle both focuses his theoretical inquiry by refining why-questions, and directs his search for empirical data by noting failures and missed predictions of earlier scientists." See also the section "The Role of *Endoxa*" in Taub's history of ancient meteorology (2003, 93–96), centered on the theoretical background of *Meteor.* I–III.

31. The two passages deal with the presence of water in compounds, water ensuring their cohesion (*Meteor.* IV.4.381b29–382a2), and with the use of analogy in reference to things that share certain properties but do not form categories that have common names (e.g., at 9.387b1–6, bones and hair are said to belong to the group of homoeomers that emit fumes when burned; Empedocles's example, incidentally, is quite different and points to the shared—protective?—function of hair, leaves, feathers, and scales).

32. This seems to be Viano's view: "Pourquoi alors, pourrait-on se demander avec raison, n'aurait-il pas utilisé les théories des prédécesseurs sur la cause materielle pour expliquer les transformations de la matière visible? La réponse peut être très simple: parce qu-il pensait que personne avant lui n'avait abordé ce domaine" (2006, 28).

The prominence of the discussion about final causation in *Meteor.* IV.12 is underscored by the insistent use of the formula "that for the sake of which" (*heneka tou* or *to hou heneka*, at 389b31, 390a4, and 390a8) and by reminders that final causes are tightly bound up with the natures and definitions of artifacts as well as of the products of nature. A certain material composition or a particular shape would not suffice for, say, a hand to actually be a hand. The hand of a dead man is a hand in name only (*homōnumōs*; 389b33, 390a1); a stone flute is a flute in name only. If a hand is to be indeed a hand, it has to display the proper dispositional properties, and, more importantly (though relatedly), it has to be able to perform certain functions,[33] and so, implicitly, it has to serve some goals.

Like Plato (significant differences notwithstanding),[34] Aristotle was not satisfied with the reductionist approach of the earlier natural philosophers (*hoi phusiologoi*).[35] The regularity observable within kinds (*genē*) and forms (*eidē*) of animals, as well as the remarkable complexity displayed by most organisms, Aristotle thought, could not possibly be the result of haphazard conglomerations of elementary particles. Rather, they have to be explained by reference to hierarchically organized final causes:[36] elements are for the sake of homogeneous stuffs, (organic) homogeneous stuffs are for the sake of the nonuniform or instrumental parts of which they are constitutive, and organs are for the sake of organisms of which they are functional parts.[37] The theoretical manifestos of Aristotle's teleology are *Physics* II (esp. chap. 8) and *PA* I.1, although many other texts are replete with explicit references to final causation.

Chapters 1–11 of *Meteor.* IV, however, rely largely on material and efficient causation to explain the nature of uniform bodies and the changes they undergo, ranging from generation and destruction to different types of alteration. Thus, the contrast between *Meteor.* IV.1–11 (and also *Meteor.* I–III) and some of the other extant scientific works by Aristotle may be perplexing at first sight. Still, a qualification is in order here. Hints at final causation are scarce but,

33. In Greek, *erga*; e.g., 390a11: seeing is the function of the eyes.

34. Whereas in Plato 'nature' is a product of *technē*, being fashioned by the divine craftsman and his aides, Aristotle, in his biology, is committed to a truly natural teleology (for a detailed account of final causation in Plato, see "Plato's Unnatural Teleology" in Lennox [2001b, 280–302]).

35. See, among other relevant passages, Aristotle's attack (in *GA* V.8) on Democritus, who had no use for final causes.

36. See, e.g., *PA* II.1.646b5ff. (elements are for the sake of the uniform parts, which are for the sake of nonuniform parts) and Lennox's comments on this section (2001a, 182); cf. *Meteor.* IV.12.

37. For a more detailed discussion about this hierarchy of levels of final causation, see Lennox's (2014) comments on *PA* II.1 and *GA* II.6 and Gill (2014).

I believe, not entirely absent from *Meteor.* IV.1–11.[38] Chapters 2 and 3, for example, hold an interesting place in *Meteor.* IV. While *pepsis*, or concoction (a process that is essential to many of Aristotle's explanations in his biological corpus),[39] is rarely mentioned in the rest of *Meteor.* IV,[40] chapters 2 and 3 deal in great detail with both complete and partial concoction. *Pepsis* is described and explained not solely in terms of a uniform body's natural heat mastering the moisture in that body, such as the pulp of a fruit, but also with a view to some *telos* ('end', 'end point', 'completion') in a process, which can be natural (e.g., fruition) or artificial (e.g., cooking).[41] A *telos* is not necessarily a final cause, but it can entail it, for instance, in contexts in which the type of concoction under discussion affects a uniform part belonging to a substance, in Aristotelian terms, such as a plant (when it comes to the production of seeds and their generative power) or a human being. Here are a couple of passages relevant to this point:

> In some cases the end (*telos*) is their nature—that is, nature in the sense of form and substantial being (*eidos kai ousian*); but in other cases the end of the concoction is a certain underlying structure (*hupokeimenēn tina morphēn*), when the moist comes to be of a certain sort and a certain amount either by being roasted or boiled or ripened or in some other way heated; for at that time the moist is useful (*chrēsimon*), and we say

38. Apart from chaps. 2 and 3, where final causes are actually invoked, albeit sketchily, in order to spell out the notion of *pepsis*, there are mentions of formal and final causes in chaps. 5 (at 382a28–30) and 10, but they are not accompanied by much elaboration. The passage in chap. 10 seems to prefigure some of the points made in chap. 12: "Since the nonuniform bodies are constituted by another cause, whereas the matter from which these are constituted is the dry and moist, and therefore water and earth (for each of these has the very conspicuous potency of one or the other of those), while the productive potencies are heat and cold (for heat and cold constitute and solidify bodies from the dry and moist), let us grasp which sorts of uniform bodies are forms of earth, which of water, and which are compounds" (10.388a20–25).

39. As Lloyd (1996, 83) notes, "'Concoction' (*pepsis*) is used in an amazing variety of contexts throughout Aristotle's natural science and most especially in his zoology, where it must rank as one of his key concepts." The generic discussion in *Meteor.* IV, comprising definitions and examples as well as a division into three species of concoction and three species of incomplete concoction, seems intended to put some order in that "amazing variety."

40. There are two mentions made in passing at *Meteor.* IV.7.384a33 (*apepton*) and 11.389b8 (*pepsasēs*). The process itself, which involves an increase in density, among other things, is described elsewhere in some detail but with no reference to a goal or, more neutrally, to an end point (*telos*) of any kind, e.g., at 6.383a14ff. and at the very beginning of chap. 7.

41. See, e.g., 3.381a2–4: "The end (*telos*) is not the same for all things, either for things being boiled or for things being concocted, but some for eating, others for drinking, and others for some other use (*chreian*), since we say that we boil drugs."

that concoction has occurred, as in the case of new wine, the compounds in tumors when they become pus, and tears when they become rheum, and so on. (2.379b25–33)[42]

And another example: "Ripening is a sort of concoction. For concoction of the nutrient in the pod is called ripening. Since concoction is a completing, the ripening is complete precisely when the seeds in the pod are able to complete another thing of the same sort—for we speak in this way of completeness in other cases too" (3.380a11–16).

Although I believe it is worth pointing out that *Meteor.* IV.1–11 is not entirely devoid of teleological accents, as I have suggested here, it is certainly the case that, unlike in chapter 12, a treatment of final causation is not a central concern of the bulk of book IV. The reader of this article should, therefore, not be surprised that I have not dwelled at length on this topic—which is so pervasive in many other Aristotelian writings—or that, as I explained earlier, I have not focused on the handling of *endoxa* in this treatise.

Conclusion

The main contribution of this article is an analysis of the ways in which demonstration, causal explanation, and division are put to work in the fourth book of the *Meteorology*, these methodological aspects being reminiscent of Aristotle's biological corpus. The general upshot of this analysis is hopefully a strengthening of the view that his more 'applied' scientific works largely follow the precepts put forth in his theory of scientific inquiry, as presented mostly in *APo*. and in *PA* I. I will not summarize my various points here; instead, I would like to return briefly to the distinction between 'the fact' and 'the reason why' and to the relation between *Meteor.* IV and the biological corpus.

A cursory reading of *Meteor.* IV might leave us with the impression that, in comparison with *PA* and *GA*, *Meteor.* IV is only centered around the 'what', *ti*, and is concerned merely with collecting and organizing facts in a generic fashion, whereas, say, *PA* (esp. II.4–9) will explain what uniform stuffs are separately (*kath' hekaston*) by providing 'the reason why', *dioti*, based, in addition to the analysis of the material constitution of the homoeomers, on functional

42. This passage is reminiscent of Plato's *Timaeus* 83de; see also the Hippocratic works *On Ancient Medicine* (beginning of chap. 19 in modern editions; note the use of *pephthēnai*) and *Affections* 34 (where the verb *pepainein*, 'to ripen' or 'to reach maturity', is used); cf. *Anonymus Londinensis* XI.43.

explanations and, implicitly, on final causation.[43] Accordingly, the fourth book of *Meteorology*, along with parts of *PA*, may seem to reflect a relationship, circumscribed in *APo*. I.13, in which the 'what' and the 'reason why' are the focus of different sciences. In *APo*. I.13, at 78b36ff., Aristotle points out that, in the case of sciences devoted either to the study of 'the fact' or to the study of 'the reason why', the former are subordinated to the latter (*thateron hupo thateron*): this is the relationship between optics and geometry, mechanics and solid geometry, harmonics and arithmetic, contemplation of fixed stars or planets and astronomy. Thus, one might assume that Aristotle's 'biochemistry' is strictly subordinated to his 'zoology', to use two convenient anachronisms.

Such a conclusion, however, should be considered with caution. Subordinate sciences, according to *APo*., display a more empirical or less theoretical[44] nature than the corresponding 'supraordinate' ones, which "possess demonstrations which give the explanations, and often they [i.e., the mathematical scientists] do not know the fact—just as people who study universals do not know some of the particulars through lack of observation" (trans. Barnes 1975/1993).[45] *PA* II.4–9 relies massively on the observation of various types of blood, fat, and so on, which allows us to discern their dispositions and, by appeal to *Meteor*. IV, to acquire insight into their material composition, so *PA* II does not appear to be any less empirical than *Meteor*. IV.[46] In practice, generic divisions like the ones made in *Meteor*. IV would have to be preceded by and would be perhaps 'more theoretical' or abstract than minute and individual observations of particular uniform stuffs. Moreover, as I suggested in my section on demonstration and causal explanation, *Meteor*. IV is very much a work on 'the reason why' (*to dioti*), except that this aspect too is situated at the level of material explanation, insofar as 'chemical' combination and structural peculiarities cause (i.e., are 'the reason for') the presence of dispositional properties like 'liq-

43. The text of *Meteor*. IV certainly uses this language on a few occasions, language that evokes the terminology of *APo*. In *Meteor*. IV.3, e.g., at 381b21–22, Aristotle concludes his discussion of concoction and inconcoction by saying: "We have now discussed what [*ti . . . esti*] concoction and inconcoction are, as well as ripening and rawness, and boiling and roasting and their opposites." I am thankful to James Lennox for drawing my attention to this passage.

44. The contrastive pair of terms is *aisthētikon*, *mathēmatikon*.

45. On the priority of some sciences with respect to others, see also *APo*.: "One science is more exact (*akribestera*) than another and prior to it (*protera*) if it is concerned both with the facts (*hoti*) and with the reason why (*dioti*) and not with the facts separately from the science of the reason why; or if it is not said of an underlying subject and the other is said of an underlying subject (as, e.g., arithmetic is more exact than harmonics); or if it proceeds from fewer items and the other from some additional posit (as e.g. arithmetic is more exact than geometry)" (I.27.87a31–35; trans. Barnes 1975/1993). For the place of *eidē* in the 'supraordinate' sciences, see *APo*. I.13.

46. For more on this, see Lennox (2014).

uefiable' and 'flexible' in homoeomers and, together with the agency of heat or cold, can account for the manifestation of such dispositions. To that extent, then, Aristotle's 'chemistry' also illustrates the situation, discussed in *APo.*, in which one and the same science deals both with 'the fact' and with 'the reason why'.

The one very important respect in which *Meteor.* IV does find itself in a position of subordination with respect to treatises like *PA* II is, of course, that *Meteor.* IV speaks at length about the potentials and constitution of uniform stuffs, without, however, providing a full picture of their natures. In other words, the material accounts presented in *Meteor.* IV.1–11 provide only a partial understanding of the uniform parts, whereas *PA* and *GA* significantly complete these accounts by refocusing our attention on the functions fulfilled by the organic homoeomers within the more complex structures of which they are constitutive parts. Even if book IV of the *Meteorology* is subordinate in this way to sections of Aristotle's biological works, I hope that my examination of the scientific method in *Meteor.* IV can assure its reader that this work still deserves our interest both for its inherent merits and for the light it can cast on the relation between the theory and practice of Aristotelian science. Had a less propitious tradition handed down to us nothing of Aristotle's 'akroamatic' notes but this treatise on homoeomers, he would probably still be no negligible figure in the history of science and philosophy of science.

To sum up, one should not overstate the autonomy of the 'chemical treatise', as there is no denying that the scientific enterprise achieved by *Meteor.* IV rests on the foundation prepared in *Generation and Corruption* (see Lennox 2014), *On the Heavens*, and, in a smaller measure, in *Meteor.* I–III,[47] and in a way finds its fulfillment in works like *PA* and *GA*. Still, although *Meteor.* IV can be—and has been—regarded as a prolegomenon to Aristotle's biology,[48] especially to those treatises or sections that deal with simple or uniform parts, this book is not simply contingent or somehow parasitic on works like *PA* II but has very much its own worth. *Meteor.* IV goes far beyond organizing uniform stuffs according to material dispositions and glimpses, as it were, at what some of those dispositions are signs of: the composition and the physical constitution of uniform materials. It explains phenomena that may be less majestic than the ones discussed in *Meteor.* I–III, rainbows and the Milky Way included, and less exciting than the morphology, physiology, and habits of exotic and not-so-exotic animals, but that are pervasively part of our lives. After all, knowing how

47. Three very good synopses of the debate regarding the relation between *Meteor.* IV and the first three books as well as other Aristotelian works can be found in Baffioni (1981), 17–33, in Louis (1982), x–xviii, and in Viano (2006), 79–113; see also Düring (1944/1980), 17–20.

48. See, e.g., Furley (1989) and, of course, the three articles gathered in this forum.

most[49] stuffs tend to behave determines to some extent our own behavior and expectations; in Nelson Goodman's words, things are full of threats and promises (1955, 40).

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49. In chap. 8 of *Meteor.* IV Aristotle notes that he is about to deal with some of the most common material dispositions, which would allow us to differentiate "the great majority of bodies" (*ta . . . pleista schedon tōn sōmatōn*; 385a19).

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