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Aristotle's Logic and Theory of Science

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Knowledge and Analysis

Aristotle's logic and theory of science have been handed down to us in two texts that are nowadays called *Prior Analytics* and *Posterior Analytics*, respectively. But Aristotle himself usually refers both to his logic and his theory of science as "analytics" (e.g., *Top.* VIII.11, 162a11–12; *Met.* Z.12, 1037b8–9; *EN* VI.3, 1139b27; *Rh.* I.2, 1356b10), and the very first sentence of the *Prior Analytics* announces an enquiry about demonstrative knowledge which is the specific topic of the *Posterior Analytics*: "First we must state the subject of the enquiry and what it is about: the subject is demonstration, and it is about demonstrative knowledge" (*APr.* I.1, 24a10–11). Hence, for Aristotle the procedure of analysis (*analusis*) is crucial for both logic and the theory of science, and his logic called *syllogistic* is simply a part of his theory of scientific knowledge and demonstration. We can only understand in which way Aristotle puts analysis to work in logic and science if we first look briefly at his basic notion of knowledge (*epistēmē*).[1]

Aristotle took over from Plato the idea that *knowledge in the proper sense* is about universal facts in the universe. However, while *knowledge of universal facts* is, for Aristotle, certainly a basic kind of knowledge, *scientific* knowledge consists in knowing the *causes* of given facts, the causes being, of course, themselves facts (*APo.* I.2, 71b9–16): First we have to establish the facts; and "when we know the fact we seek the reason why" (*APo.* II.1, esp. 89b29–31). In this way, science (*epistēmē*) is, on the one hand, a specific state of the knowing subject, and, on the other hand, the set of specific theories we have – according to adequate methods – established and grasped if we are in the specific epistemic state called science.

Aristotle cares a lot about reliable methods of establishing facts; but his main concern in the *Analytics* is the methodology of finding causes for given facts. Given that all animals have a stomach we want to know *why* that is so. A first idea might be that all animals take in food from outside and therefore need an organ for receiving and digesting food, and this is just the stomach (*PA* III.14, 674a12–19). Given that all statues made of metal are heavy we want to know why. An answer might be that all these statues are of bronze and bronze is a pretty heavy metal. Finding out about causes of given facts clearly comes down, *linguistically* speaking, to looking for adequate

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premises for a given *conclusion.* More specifically, if we note, as Aristotle did, the standard form of a predication *C is an A* inversely as *A belongs (as a property) to C's* (let us abbreviate this by AC), scientific knowledge of AC provides, in the simplest case, premises AB and BC for AC such that the new term B points to the cause. For instance, why does being heavy (A) belong to statues of metal (C)? Because there is a property *consisting of bronze* (B) such that being heavy belongs to all things consisting of bronze (AB) and consisting of bronze belongs to statues of metal (BC).

It is at this point that we can see how the procedure of analysis enters the picture. The underlying idea is that, in general, knowledge of a domain entails knowing all the simplest parts of this domain (*Phys.*I.1, 184a9–14; *Met.* Η.1, 1042a5–6), and the method of theoretically dividing a domain into its simplest parts is called *analysis* (*EN* III.3, 1112b20–24). Analysis can be applied, for instance, to means–end relations in ethics (*ibid.*) and to two-dimensional diagrams in geometry (*Met.* Θ.9, 1051a21–26),[2] but is used most prominently in logic (*APr.* I.44, 50b30, 51a1–3) and science (*APr.* I.32, 47a3–5; *APo.* I.12, 78a7; I.32, 88b15–20; II.5, 91b12–13). In particular, if we seek, in a scientific enterprise, the causes of given facts, this is an important case of analysis: we try to analyze given facts in terms of further facts that point to causes of the given facts. Linguistically speaking, we try to analyze, in the simplest case, a given proposition AC by providing a third term B such that AB and BC are premises of the conclusion AC and thus, AC is analyzed into AB and BC. The two premises have one term, the *middle term*, viz. B, in common; the other two terms, viz. A and C, are called *extremes*. If there are no more middle terms such that AB and BC can themselves be analyzed, AB and BC are *immediate*, i.e. are the *simplest* logical parts of AC. This can be illustrated by the formula:

D   A: AB – BC: C

If, however, there are more middle terms such that the premises AB and BC can themselves be further analyzed, the analysis has to be continued until we get to immediate premises. This amounts to, as Aristotle calls it, *thickening* AC by filling AC with all the middle terms we have found (*APo.* I.23, 84b19–85a1). For instance, let B, D, E be all the middle terms we can find for AC, such that AB and BC are premises of AC and AD and DB are in turn immediate premises of AB, while BE and EC are immediate premises of BC, then this can be illustrated by the formula:

D*   A: AD – DB – BE – EC: C

To be sure, this kind of analysis is analysis in empirical sciences, *not* in syllogistic. Even from the thin description of this sort of analysis that I have presented so far it becomes evident that scientific analysis is basically a *bottom-up procedure,* not a top-down procedure; it starts from given facts or conclusions, and looks for causes and premises,

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2.   In geometry, circle and straight line are the simplest parts of the geometrical continuum; this is why proofs in geometry have to use compasses and ruler: constructing diagrams by using compasses and ruler comes down to analyzing the diagrams into their simplest parts.

and maybe for causes of these causes and premises of these premises. Analysis looks for *sufficient* premises of given conclusions and is, therefore, *not* a deductive method.

The Relation Between Prior and Posterior Analytics

So far, we have been talking in a quite informal way. Interestingly, Aristotle's definition of a deduction at the beginning of the *Analytics* looks quite informal too: "A deduction (*sullogismos*) is a discourse in which, certain things being posited, something other than the things laid down follows of necessity in virtue of the fact that they are these" (*APr.* I.1, 24b18–20; similarly *Top.* I.1, 100a25–27). Some scholars are worried about this definition, since it does not seem to be connected with a notion of logical validity. It has even been argued that Aristotle's definition of deduction reflects an early stage in the development of his theory of science and demonstration that did not presuppose formal syllogistic as presented in the *Prior Analytics* (Barnes, 1969, 1981; Solmsen, 1929). There is a good deal of evidence for this chronological guess. The *Prior Analytics* is in many technical respects far more developed than the *Posterior Analytics*, and it is obviously designed to solve a number of proof-theoretical problems posed by an informal sketch of a theory of demonstration. The most important of these problems is *which* premises are *good* premises for a given conclusion and *why* they are good ones. It is primarily these questions that the syllogistic seeks to answer. This implies also that the initial informal concept of deduction be restricted to a formal notion of deduction based on the idea of logical validity. In addition, given the idea that scientific knowledge is primarily concerned with the universal it is small wonder that a logic that is supposed to provide a sound logical foundation for the theory of science is mainly concerned with analyzing the logical relations between universal and particular quantified propositions. That is why, to use modern terms, Aristotle's syllogistic is, not a propositional logic, but a first-order predicate logic.

All this is, of course, fully consistent with the view that in the *Analytics* as we read it today, syllogistic is the official logic of the theory of science. That is, we must take the syllogistic (the *Prior Analytics*) to be what Aristotle says it is: *theoretically* preliminary to the theory of science (the *Posterior Analytics*) (see e.g., *APr.* I.4, 25b26–31; Smith, 1989, p. xiii; Detel, 1993, vol.1, pp. 110–14).

Syllogistic

In presenting a logic that is helpful for a theory of science, Aristotle first determines a canonical form of syllogistic propositions: A *syllogistic proposition* is either a universal affirmative or a universal negative or a particular affirmative or a particular negative proposition, i.e. has one of the following four forms:

1. A belongs to every B (in short AaB);
2. A belongs to no B (in short AeB);
3. A belongs to some B (in short AiB);
4. A does not belong to some B (in short AoB)

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(where A and B are usually one-placed universal terms and a, e, i, o are the *syllogistic relations*) (*APr.* I.2, 25a4–5).

As we have seen, the basic form of an argument based on an analysis, for instance in science, consists of two premises and a conclusion. Therefore, Aristotle looks, in his syllogistic, at forms of ordered sequences of three syllogistic propositions. In particular, he examines deductions having as premises two syllogistic propositions sharing one term, and this is the case, if the common term is either subject of one premise and predicate of the other, or subject of both premises, or predicate of both premises. In this way, he gets exactly three different forms of such sequences – called *syllogistic figures* – concerning a given conclusion AC.[3] In general terms, these figures are as follows:

(1) $A \times B, B \times C \Rightarrow A \times C$; (2) $B \times A, B \times C \Rightarrow A \times C$; (3) $A \times B, C \times B \Rightarrow A \times C$
(where x is one of the four syllogistic relations and A, B, and C are variables for universal terms).

The logical tradition usually calls an ordered sequence of syllogistic propositions that has the form of one of the three syllogistic figures a *mood.* Clearly, there are 192 $(= 3 \times 4 \times 4 \times 4)$ moods.

It is the *most important task of Aristotle's syllogistic* to determine *which of the 192 moods are syllogistically valid.* And it is in formulating and solving this problem that we can see Aristotle as being the first thinker to fully grasp the idea of a formal logic. The crucial proposal is that there are four deductions in the first figure that are *perfect*, i.e. such that the conclusion follows *evidently* of necessity from its premises. These *perfect deductions* are:

A1   AaB, BaC $\Rightarrow$ AaC (*Barbara*)
A2   AeB, BaC $\Rightarrow$ AeC (*Celarent*)
A3   AaB, BiC $\Rightarrow$ AiC (*Darii*)
A4   AeB, BiC $\Rightarrow$ AoC (*Ferio*)

Aristotle justifies his claim that **A1** and **A2** are perfect deductions by saying: "we have already explained in which way we say: being predicated of all" (*APr.* I.4, 25b39–40, cf. I.1, 24a18), and: "it has been defined in which way we say: being predicated of none" (*APr.* I.4, 26a27; cf. I.1, 24a18–19).[4] Although Aristotle did not have a clear notion of meaning, it seems evident that *he in fact justified the logical validity at least of* **A1** *and* **A2** *by pointing to the meaning of the syllogistic relations a and e:* in general terms,

3.   This procedure might provide an explanation why Aristotle never mentions a fourth syllogistic figure that could be constructed by changing the order of the terms in the premises, i.e., $B \times A, C \times B \Rightarrow A \times C$ (he does discuss deductions of this form, though, but treats them as deductions of the first figure) (Patzig, 1968, Smith, 1989).
4.   Indeed it suffices to talk about A1 and A2 alone because, as Aristotle later correctly notes, A3 and A4, although belonging to the perfect deductions the validity of which can be justified by the way we talk about the syllogistic relations, can nevertheless be proved on the basis of A2 (the proofs are presented in *APr.* I.7, 29b1–14).

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deductions are logically valid if they are valid only in virtue of the meaning of the logical constants they contain. That is why we can use, in doing formal logic, variables for the non-logical vocabulary, as Aristotle does for the first time in the history of thought: such is the conception of formal logic.

Furthermore, it is evident that given the way we use the syllogistic relations we can propose:

L1 $AeB \Rightarrow \neg (AiB)$
L2 $AaB \Rightarrow \neg (AoB)$

Finally, Aristotle takes it that the principle of indirect proof (which he calls the principle of *deductions leading to the impossible*) is valid, for instance in the following form:

RI Let R, S, T be three syllogistic propositions, then,
if the deduction $\neg T, S \Rightarrow \neg R$ is valid, the deduction $R, S \Rightarrow T$ is valid too.

There is no justification of **RI** in the *Prior Analytics* (only a discussion in I.29), but since **RI** follows from the principle of the excluded middle which is in turn extensively defended in *Met.* Γ, we can recognize **RI** as at least indirectly justified.

Assumptions **A1 – A2**, **L1 – L2** and **RI** are a sufficient logical foundation for approaching the next challenge the syllogistic has to meet: to *prove syllogistically* which moods of the second and third syllogistic figure are syllogistically valid. It is in connection with grasping the notion of a logical proof and with constructing effectively such proofs that the conception of analysis again proves to be helpful. And it is here that we can see how Aristotle puts analysis to work *in his syllogistic*.

The basic idea is that if $R, S \Rightarrow T$ is a deduction that is not perfect, a *syllogistic proof* of this deduction consists in *analyzing it into perfect or already proved deductions.* This kind of *syllogistic analysis* comes down to filling the gap between premises and conclusion of the deduction with perfect or proved deductions. The general scheme for the syllogistic analysis of the deduction D $(R, S \Rightarrow T)$ is accordingly the proof formula:

P $R, S: D_1 (R,S \Rightarrow X_1) - D_2 (X_2,X_3 \Rightarrow X_4) - \ldots - D_n (X_{n-1},X_n \Rightarrow T): T,$

where the Ds are perfect or proved deductions such that the first of them starts with the premises of the deduction that is to be proved and all following ones use as premises two of the syllogistic propositions that show up before in the row (R, S, or the X_i) until T is reached. In this way, deduction D is indeed analyzed into deductions $D_1 - D_n$. Proofs in Aristotle's syllogistic are analyses, not of syllogistic propositions into other syllogistic propositions, but of deductions into other deductions.[5]

5. Aristotle does not use the notion of analysis in this context, but says rather that the imperfect deductions are *completed by*, or *reduced to*, perfect deductions and conversion rules by *making them perfect by certain supplementary assumptions* (the supplementary assumptions simply being perfect deductions and conversion rules) (e.g. *APr.* I.5, 28a1–9; I.6, 29a14–17, I.7, 29b1–2). But this *is* the description of a kind of analysis; indeed, it would be odd to assume that Aristotle calls his syllogistic theory *Analytics* without being willing to see the most important part of this theory as a case of analysis.

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The first deductions Aristotle proves are not moods, but simpler deductions with only one premise, namely the *conversion rules* (*APr.* I.2, 25a14–25):

K1   AeB ⇒ BeA;   **K2**   AiB ⇒ BiA;   **K3**   AaB ⇒ BiA.

The conversion rules are frequently used in proofs of valid deductions in the second and third figure (these deductions are called *imperfect* because they need to be proved). Hence, it is possible that in the proof formula **P** stated above R = S or $X_i = X_{i+1}$. According to Aristotle, among the 188 moods that must be checked for logical validity, only 14 prove to be syllogistically valid. Two typical proofs or logical analyses run as follows:

(a)   Proof of BaA, BeC ⇒ AeC (Camestres, second figure):
      BaA, BeC: **K1** (BeC ⇒ CeB) – **A2** (CeB, BaA ⇒ CeA) – **K1** (CeA ⇒ AeC): AeC
(b)   Proof of AiB, CaB ⇒ AiC (Disamis, third figure):
      AiB, CaB: **K2** (AiB ⇒ BiA) – **A3** (CaB, BiA ⇒ CiA) – **K2** (CiA ⇒ AiC): AiC

These proofs obviously satisfy formula **P**, i.e., are genuine logical analyses.[6]

Interpretations of Aristotle's Syllogistic Logic

Aristotle's *Prior Analytics* contains much more than just the so-called *assertoric syllogistic* outlined above. Much of this additional material is designed to help solve problems emerging from the theory of science. Most prominently, since a scientific theory often uses *modal propositions* (primarily *necessary* ones) Aristotle develops a *modal syllogistic* (*APr*. I.8–22) that leaves unsolved, though, a number of serious problems. For instance, Aristotle seems to use the modal operators in an ambiguous way: sometimes he reads **N**AaB (where N abbreviates *necessary*) as *it is necessary that AaB* (the so-called *de-dicto*-reading), but sometimes as *Every necessary-A belongs to B* (the so-called *de-re*-reading). This is one of the reasons why scholars have sometimes extreme difficulties understanding why Aristotle calls some modal deductions valid or invalid, respectively (Patterson, 1995; Striker, 1994).

Assertoric and modal syllogistic are supposed to show *how every deduction comes about*, as Aristotle says. But in addition, there are two more projects in *Prior Analytics* I (cf. *APr*. I.32, 47a1–4): first, to define a way in which deductions may be found (chs. 27–31), and second, to show how a given informal deduction can eventually be transformed into a deduction *in the figures* (chs. 32–45) (this transformation is another kind of *analysis*). *Prior Analytics* II is best seen as discussing technical concepts of dialectic in terms of syllogistic theory and as trying to solve further proof-theoretic difficulties showing up in the *Posterior Analytics* (Smith, 1989).

For a long time scholars tried to read Aristotle's syllogistic as an axiomatic system in the modern sense (Lukasiewicz, 1957; Patzig, 1968), the perfect deductions being

6.   Aristotle does not only show which moods are syllogistically valid, he also shows which are invalid. And he does this pretty much in the same way modern logicians do it – by providing countermodels.

the axioms and the imperfect deductions the theorems. But according to this reading we would need some more deduction rules to get from axioms to theorems, including theorems from *propositional* logic. There are no such rules to be found, though, in the text of the *Prior Analytics*. Therefore, according to the axiomatic reading Aristotle's syllogistic is formally incomplete. However, it is much more natural, and corresponds much more closely to formula **P** that is actually used in the text, to look at the perfect deductions as *inference rules* that are inferentially primitive (but are, of course, semantically justified as truth-transmitting). This interpretation looks at syllogistic as a system of natural deduction in the modern sense (Corcoran, 1974b; Smiley, 1973; Smith, 1989). It presupposes what Aristotle seems in practice to assume, namely that *no* universal term is empty. Under this reading Aristotle's syllogistic proves to be both sound and formally complete (Corcoran, 1974b).

Knowledge of Facts

Knowledge of facts is, for Aristotle, the foundation of scientific knowledge (*APr.* I.27, 43b1–38; *APo.* I.23, 84b19–85a1).[7] Accordingly, Aristotle is concerned, not only with the methods of establishing scientific knowledge, but also with scientific methods of establishing knowledge of facts. For instance, he recommends to state facts in such a way that they can be more easily incorporated into scientific inquiries; thus, we should use an adequate terminology and should avoid homonymy and ambiguities (*APo.* II.13, 97b30–36; II.17, 99a4–15) (Lennox, 1994). Sometimes facts can even be deductively established, and this is one of the reasons why we must carefully distinguish between deductions from symptoms and deductions from causes (*APo.* I.13, 78a22–b11). Sometimes scientific research starts from facts that most people recognize. For instance, asked *what thunder is* most people would say *that* thunder is a certain noise in the clouds. Propositions describing these facts are, therefore, a sort of *definitions* (so-called *nominal* definitions) that do not need justification and can serve as possible *conclusions* of scientific explanations (*APo.* II.10, 93b29–32, 94a14).[8]

One way of establishing universal facts is *induction*. Aristotle claims that "we learn either by induction or by demonstration and that it is impossible to consider universals except through induction" (*APo.* I.18, 81a39–b2). He even says that, in a sense, we become familiar with the immediate premises of science by induction (*APo.* II.19, 100b3–4). Scholars disagree about how Aristotle conceived of induction. Is it a form of *argument* leading from a finite set of singular premises to a universal conclusion (Ross, 1957), pretty much in the modern sense? A minority of scholars denies this and claims that an Aristotelian induction is simply a list of singular facts sharing a structure and is, therefore, not an argument at all (Engberg-Pedersen, 1979). According to this view, universal assumptions cannot be inferred from singular propositions, but

7. That facts are a domain of *knowledge* is explicitly suggested at the beginning of *APo.* I.13.
8. For a sophisticated and far-reaching analysis of the status of facts in zoology, especially concerning the classification of animals, see Pellegrin (1986). Pellegrin shows that these facts do not have scientific status and cannot be related to a taxonomic project (in sharp opposition to the traditional interpretation).

must rather be already presupposed for classifying singular facts and establishing an induction. Indeed, there is not a single passage in which Aristotle unambiguously calls the *transition* from singular to universal propositions an induction. We must be careful not to read formulas like *this is evident by induction* or *secured by induction* (*Phys.* I.2, 185a14; *Top.* IV.2, 122a19) as pointing to a procedure of deducing or concluding; rather, these formulas are fully consistent with the claim that it is by looking at certain singular facts or propositions as *heuristic devices* that we can make a good *guess* about a universal. Looking at some things *and* classifying them under *presupposed* universals as swan and white (the finite list of these things *thus described* forming the induction) we may *guess*, not conclude, that all swans are white. This guess holds good as long as we do not encounter a swan that is not white (*Top.* II.3, 110a32–36; VIII.2, 157a34–b33; *APr.* II.26, 69b1–8; *APo.* I.4, 73a32–34; II.7, 92a37–38).

Aristotelian Causes

As already mentioned, Aristotle thinks that science builds on the knowledge of facts to explain them by finding out about their causes (*aitiai*). It is important, though, not to confuse Aristotelian causes with causes in the modern sense. To be sure, there is no agreement among modern philosophers about how best to analyze the difficult notions of cause and causation, but the standard view is that causes are earlier than, and sufficient for, their effects and are based on natural laws. It follows that if we know some cause and the appropriate natural law, we can predict that the effect will come about. Aristotelian causes are in important respects different. Here are some examples: (i) the fact that statues are of bronze is an Aristotelian cause of the fact that these statues are heavy; (ii) the fact that the moon is in the middle between sun and earth is an Aristotelian cause of the fact that the moon is eclipsed, and (iii) to stay healthy is an Aristotelian cause of walking after dinner and other activities suggested by medicine and dietetics; finally, (iv) the fact that a string is divided according to the ratio 1:2 is an Aristotelian cause for the fact that the string produces an octave. In such cases, the cause is not later than, and sufficient as well as necessary for, its effect (*APo.* II.12, 95a10–24; II.13, 97a35–b24) and does not involve a notion of natural laws (it is only later in Stoic philosophy that the concept of a natural law begins to emerge, see Frede, 1989). Therefore, knowing an Aristotelian cause does not permit us to predict its effects; rather, from effects we can infer their Aristotelian causes (*APo.* II.12, 95b22–37). All this is a clear indication that Aristotelian causes are not causes in the modern sense. Aristotle's key idea is that a *cause* of an effect is a fact that can *answer the question why* the effect comes about. And he feels that there are *four kinds of answers to why-questions*: one points to the *material* of the thing in question (as in case (i)), another points to the *origin of its movement* (as in case (ii)), a third mentions it's *aim* (case (iii)), and a fourth looks at its *form* (case (iv)). This is the *Aristotelian doctrine of the four causes*: the material, efficient, teleological and formal cause (cf. *Phys.* II.3).[9] Hence, a fact BC is an *Aristotelian cause* of another fact AC iff the B-property of C can

9. On causes in Aristotle's *Physics*, see Bodnár and Pellegrin, ARISTOTLE'S PHYSICS AND COSMOLOGY.

be classified as material, origin of movement, aim or form in relation to the A-property of C.

A short additional note about the teleological cause seems in order. From early modern times on many philosophers and scientists have seriously criticized the notion of a teleological cause because this cause seems to exercise an influence of the future on the past. This objection is, however, clearly based on falsely reading the modern understanding of a cause into the notion of an Aristotelian cause. According to Aristotle, BC is a teleological cause of AC if, roughly, there is a regular development of states of C such that usually BC is the final and most developed state of C and AC is a regular former state in the development of C such that AC is necessary for reaching BC. This is one way of explaining why C gets into state AC. This idea is empirically contentful, consistent and by no means absurd; in particular, it in no way involves that the future can exercise any influence on the past or the present (Gotthelf, 1987b).

Aristotelian causes and their effects are connected, not by a natural law, but by a universal empirical regularity. That is to say: BC's being an Aristotelian cause of AC involves that AaB is a universal fact of the universe. A full explanation of AC has therefore to mention, not only the cause BC, but also the regularity AaB (cf. *Phys.* II.8).

Demonstration

The opening sentence of the *Analytics* shows that the idea of a demonstration, and of scientific knowledge based on demonstrations, lies at the heart of Aristotle's logic and theory of science. To adequately understand this idea it is important not to confuse valid deductions, proofs, and demonstrations – even more so, since the Latin formula *quod erat demonstrandum* is nowadays well known for resuming *proofs*. But for Aristotle a deduction is, as we have seen, *syllogistically valid* iff it is a perfect or imperfect deduction in the technical sense; a valid deduction is, in turn, a *proof* iff its premises can be taken to be true; and finally, a proof is a *demonstration* iff its premises reveal an Aristotelian cause. Aristotle himself uses the same term (*sullogismos*) for both valid deductions and proofs, but a different term (*apodeixis*) for demonstrations.

According to the *Analytics*, every demonstration is a sort of valid deduction (*APr.* I.4, 25b29–31) and so has the form of one of the syllogistic figures (*APr.* I.23, 41b1–5; I.25, 41b36f.); there is *no* demonstration without middle term (*APo.* I.23, 84b23–25), and in particular the first syllogistic figure proves to be most important for demonstrative sciences (*APo* I.14). That is why syllogistic plays a crucial role for Aristotle's theory of science. His notion of a demonstration shows clearly that he conceived of the crucial scientific activity as constructing *logically valid explanations of given facts revealing universal relations between (Aristotelian) causes and effects.*[10] We can

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10. This idea has been rediscovered in the twentieth century philosophy of science in the famous article by Hempel and Oppenheim on the structure of a hypothetical-deductive explanation (note that the authors do not rely, in this article, on a modally qualified notion of cause, but only on the idea of a universal empirical regularity, pretty much like Aristotle some 24 centuries earlier), see Hempel and Oppenheim (1948).

use examples (i) to (iv) for Aristotelian causes mentioned in the preceding section to construct demonstrations that instantiate this idea:

(i)*   Statues of metal are heavy because, first, bronze is heavy and, second, statues of metal consist of bronze;[11] symbolic notation:
         (a)   being heavy **a** *being of bronze*;
         (b)   *being of bronze* **a** statues of metal;
   ⇒   (c)   being heavy **a** statues of metal
(ii)*   The moon is eclipsed because, first, whenever something in the sky is in the middle between sun and earth it is eclipsed, and, second, the moon is in the middle between sun and earth; symbolic notation:
         (a)   being eclipsed **a** *being in the middle between sun and earth*
         (b)   *being in the middle between sun and earth* **b** moon
   ⇒   (c)   being eclipsed **b** moon
(iii)*   To digest food requires walking after dinner etc. because, first, staying healthy requires walking after dinner etc, and, second, it is the aim of digesting food to stay healthy; symbolic notation:
         (a)   walking after dinner etc. **a** *staying healthy*
         (b)   *staying healthy* **a** digesting food
   ⇒   (c)   walking after dinner etc. **a** digesting food
(iv)*   A string produces sounds in an octave because, first, producing sounds in an octave requires being divided according to the ratio 1:2 and, second, this string is divided according to the ratio 1:2; symbolic notation:
         (a)   producing sounds in an octave **a** *being divided according to ratio 1:2*
         (b)   *being divided according to the ratio 1:2* **b** string
   ⇒   (c)   producing sounds in an octave **b** string
              (where **a** is the relation *belongs to all* and **b** the relation *belongs to*).

Obviously, all four arguments are demonstrations, i.e. valid explanatory deductions in the technical Aristotelian sense: they are proofs in one of the syllogistic figures, their minor premises (b) points to one of the Aristotelian causes for fact (c), and their major premises (a) states a universal relation between cause and effect. In many cases the conclusion of a demonstration, i.e. of a scientific explanation, is itself a universal fact (as in (i)* and (iii)*); in this case, both the major and the minor premises must also be universal. But Aristotle feels that there are sometimes also scientific explanations of singular facts (as in (ii)* and (iv)*) (for examples see *APr.* I.33, 47b21–34; II.27, 70a16–20; *APo.* I.24, 85b30–35; I.34, 89b13–15; II.11, 94a37–b8); in this case, while the major premise remains universal, the minor premise can be singular too. Some of the singular facts that can be demonstrated are even contingent, for instance the fact that the Persian war came upon the Athenians (*APo.* II.11, 94a37–b8). This is not inconsistent with Aristotle's claim that there is no demonstration and no

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11.   For much more sophisticated examples of explaining phenomena by referring to matter, for instance, the formation of metals in the ground, see Gill (1997) in her illuminating discussion of *Meteor.* IV.12.

demonstrative knowledge of the contingent (*APo.* I.6, 75a18–21; I.30). The Athenians could have decided not to attack Sardis, and in this case the Persians would probably not have waged a terrible war with the Athenians; but given that the Athenians first sacked a big city like Sardis, and given the military strength of the Persians and their struggle for power, it was necessary, and we can explain demonstratively, that the Persians made war with Athens. To be sure, Aristotle thinks that demonstrations of universal facts are better and more scientific than demonstrations of particular facts (this is the claim of *APo.* I.24); but nevertheless, he does by no means exclude scientific explanations of particular facts.

Constructing demonstrations remains a *bottom-up procedure*; as Aristotle often emphasizes, first we state the facts we want to explain, and then we look for their causes by searching for premises that logically imply, and explain by pointing to an Aristotelian cause of, the given fact (e.g. *APo.* II.1–2). Sometimes there are *different demonstrations* for a given fact: there is *not* a unique demonstration for every given fact. And doing good science involves usually constructing *whole nets of connected demonstrations*, for in many cases the premises of a given demonstration can themselves be demonstrated; in these cases the question what the *decisive* cause is supposed to be becomes urgent (all this is extensively discussed in *APo.* II.16–18).

Principles

Constructing demonstrations is first to analyze, by way of a bottom-up procedure, a given fact or conclusion until all immediate deductive premises of the conclusion are discovered, and then to decide which of these premises can be classified as Aristotelian causes. The immediate premises every given demonstration depends on are called *primitives* (*prōta*) or *principles* (*archai*) (of this demonstration) (*APo.* I.2, 72a5–9). More generally, we can talk about principles of a whole scientific area, i.e., of the whole net of connected demonstrations that make up the scientific theory of this area. Aristotle calls principles of this sort *definitions* (*horismoi*) (*APo.* I.2, 72a19–22).

But if we define, say, the cold and the hot, or numbers of some kind, this does not in itself imply that they *exist*. Some sciences, such as geometry, can sometimes prove that certain entities exist (in the case of geometry, for example, by showing how they can actually be constructed); but every specific science must assume without proof that the fundamental entities in its domain exist. Sometimes it is evident that these entities exist; for example, it is evident that the cold and the hot exist. But sometimes this is less evident, as in the case of numbers (*APo.* I.10, 76b15–23). Nonetheless, these existence assumptions, although not being parts of demonstrations, are principles of a sort that have to be assumed. Aristotle calls them *suppositions* (*APo.* I.2, 72a19–21).

Finally, what about the inference rules provided by syllogistic or the more general logical principles like the principle of the excluded middle? Since demonstrations are valid deductions, these principles are also to be presupposed for any specific science that proposes demonstrative explanations. Like suppositions, they do not show up as parts (i.e., premises or conclusions) of demonstrations; but unlike suppositions, they hold in every demonstrative science. This is the third kind of principles Aristotle recognizes; he calls them *postulates* (*APo.* I.2, 72a15–18).

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The way Aristotle determines the three kinds of principles is not without problems, and consequently scholars have different views about how exactly the principles have to be interpreted. Thus, it is doubtful whether definitions have existential impact, whether suppositions are nothing more than existence assumptions, and whether all postulates hold in all sciences or some of them hold in more than one, but not necessarily in all, sciences. It seems rather clear, though, that definitions in the full sense, i.e., as highest premises of actually constructed nets of demonstrations, do have existential impact, while this might not be evident for nominal definitions. Moreover, the examples of suppositions Aristotle hints at suggest that at least an important kind of scientific supposition is existence assumptions about fundamental entities of specific sciences (more precisely, if G is the specific domain or *genus* of a specific science, about Gs). And finally, at least the paradigm cases of postulates, i.e., logically valid inference rules, hold obviously in all sciences.

In any case, definitions are the only principles that are parts of demonstrations. Consequently, Aristotle devotes a considerable part of the second book of the *Posterior Analytics* to a discussion of the relation between demonstrations and definitions (*APo.* II.1–10). The way Aristotle describes this relation is crucial for our understanding of his theory of science; but first of all it should be emphasized that in the framework of this theory definitions are *not*, as older readings have it, analytic propositions in the modern sense (i.e., propositions that are true in virtue of the meanings of the words they contain); rather, definitions are, for Aristotle, universal propositions having *empirical* (or *mathematical*) content.

Definitions and Demonstrations

Aristotle claims that there is a close connection between definitions and demonstrations. "What is an eclipse? Privation of light from the moon by the earth's screening. Why is there an eclipse? Or: Why is the moon eclipsed? Because the light leaves it when the earth screens it" (*APo.* II.2, 90a15–17). "What is thunder? Extinction of fire in clouds. Why does it thunder? Because the fire in the clouds is extinguished" (*APo.* II.8, 93b8–9). "In all these cases it is evident that what it is and why it is are the same" (*APo.* II.2, 90a14–15). These examples show how we have to understand the close relation between *the what it is* (definitions) and *the why it is* (demonstrations): the definiens of a good definition that has explanatory power is just the middle term pointing to an Aristotelian cause in the corresponding demonstration.

Let us assume, as Aristotle does, that thunder or a certain noise in the clouds that we used to call thunder (A) is adequately defined by extinction of fire in the clouds (B) (so that A:=B is true, which implies, of course, AaB and BaA), then for any C such that A and B belong to C we get the demonstration A:=B, BC $\Rightarrow$ AC. In particular, dependent on the way we determine the extremes we get a particular or a universal demonstration, respectively: If A is thunder and C some clouds up there, then we explain, why there is thunder in those clouds up there: because there is an extinction of fire in the clouds up there and thunder *is* an extinction of fire in the clouds, i.e., we get the particular demonstration A:=B, BbC $\Rightarrow$ AbC. If, however, we take *certain noise in the clouds* (A) and *thunder* (C) as extremes and the explanatory middle term (B) again as

extinction of fire in the clouds, then we can explain why thunder is a certain noise in the clouds: because thunder is an extinction of fire in the clouds and the certain noise in the clouds we used to call thunder *is* an extinction of fire in those clouds, i.e. we get the universal demonstration A:=B, BaC $\Rightarrow$ AaC (in *APo.* II.8, Aristotle offers both alternatives as possible symbolization).

The decisive message we get from these and other examples is that "without a demonstration you cannot become aware of what a thing is" (*APo.* II.8, 93b17–18). That is to say, whether a given universal syllogistic proposition is a definition can only be determined if it shows up as an explanatory premise in a demonstration we have actually constructed. However, as Aristotle adds in discussing the demonstrative explanation of thunder sketched above, "if there is another middle term for this, it will be from among the remaining accounts" (*APo.* II.8, 93b12–14): we must remind ourselves that it may be possible to explain, in turn, the premises of our explanation of thunder; in this case, we will get higher definitions out of our demonstrations. So there might be mediate definitions: only if, in the context of the entire theory of thunder possibly consisting of a hierarchy of demonstrations, we get finally to the highest immediate definitions, have we discovered definitions as *principles*. The crucial point here is that Aristotle does *not* think that we first grasp the definitions as principles and then try to explain, and demonstrate, certain phenomena by using the definitions; on the contrary, *it is only from successful explanatory demonstrations and whole theories that we can get a grip of the principles of a science.*

In particular, to grasp definitions as highest principles, we have to carry out a thorough scientific analysis of the whole domain in question. While this is basically a bottom-up procedure, it obviously provides many more premises than conclusions. Therefore we can, *after* having completed the analysis and the construction of the corresponding demonstrations, take the premises we have established and *deduce* from them, in a *top-down* manner, more conclusions. Doing this for *every* proposition about the given domain, i.e., showing how a given domain can be analyzed into *all* its elements, is to *axiomatize* our theory in an *Aristotelian* way. As Aristotle remarks correctly, in the end the number of premises and conclusions will be, in this sort of axiomatization, more or less equal (*APo.* I.32, 88b4–7). Aristotle's idea of an axiomatization is not to compress the content of a whole theory into as few axioms as possible, but rather to analyze, and thereby to see more clearly through, the content of a scientific theory.

Having grasped the principles of a scientific domain is to be in the highest epistemic state, *insight* (*nous*) (*APo.* II.19, 100b7–12); therefore, insight can itself be called the principle of knowledge (*APo.* II.19, 100b12–16). More generally, as has been mentioned above, p. 246, having insight into a given domain is to have knowledge of the simplest parts of this domain. In particular, in science insight is the "assumption of immediate premises" (*APo.* I.33, 88b35–89a4). But since it is on the basis of experience that notions of universals are formed in the soul, the principles *as being universal propositions* can be grasped (in a weak sense) by experience (*APr.* I.30; *APo.* II.19). However, experience cannot give us insight into the *immediacy*, *deductive position*, or *causality* of universal syllogistic propositions. Therefore, to grasp principles in the full sense, i.e., to come to see which propositions are the highest immediate explanatory definitions of a departmental science, requires the actual construction of the net of demonstrations

that make up this departmental science. *Therefore, doing science successfully does not begin, but rather ends up with, having insight in the fullest sense.*

Necessity

At the beginning of the *Posterior Analytics* Aristotle makes it clear that knowledge of a thing is not only awareness of what the cause of the thing is, but also an awareness that "it is not possible to be otherwise" (*APo*. I.2, 71b9–12), i.e., that it is *necessary* (*anankaion*). This is a truism, of course, since demonstrative conclusions are logically necessary in relation to their premises. But Aristotle proceeds to claim that *premises* of demonstrations are necessary too (*APo*. I.6, 74b15–18). Some scholars read a passage in the *Posterior Analytics* (I.4, 73a21–24) even as arguing that the necessity of demonstrative premises *follows* from the necessity of its conclusion, although Aristotle emphasizes elsewhere that this is not a valid inference in modal syllogistic (*APo*. I.6, 75a1–4). It is important to be clear about the precise sense in which Aristotle calls demonstrative premises necessary and even necessarily true, if only to avoid the impression that the necessary truth of definitions and other demonstrative premises implies their epistemological certainty.

It is telling that in the crucial passage that describes the key features of demonstrative premises necessity is missing: Demonstrative premises have to be "true and primitive and immediate and more familiar than and prior to and explanatory of the conclusion" (*APo*. I.2, 71b21–23). Scholars have argued, correctly, that two of these six features, viz. immediacy and explanatory power, entail the other four (see Barnes, 1975, pp. 98–9; Detel, 1993, vol. 2, pp. 62–3). Basically, therefore, highest demonstrative premises are immediate and point to Aristotelian causes. We must conclude, then, that the necessity of demonstrative premises is closely tied to these two characteristics. Indeed, Aristotle is making two different claims: First, if a necessary conclusion can be *deduced* from premises, it does *not* follow that the premises are necessary (*APo*. I.6, 75a1–4); but second, if a necessary conclusion can be *demonstrated* from premises, it *does* follow that the premises are necessary too (*APo*. I.4, 73a21–24; I.6, 74b15–17). And AB is supposed to be a *necessary demonstrative premise* iff A belongs in itself to B or B belongs in itself to A. As Aristotle's examples show, *belonging in itself* is, metaphysically speaking, an *essential* relation. But he explains this relation *epistemologically* by saying that A *belongs in itself* to B iff AaB and BaA are true and A belongs to the definition of B (*APo*. I.4, 73a34–b5). And he adds that if A belongs in itself to B, then A is not said about B as underlying subject (which comes down to saying that A is at least partially (in case of a definition A:=B even fully) identical with B), and A belongs to B because of itself (which comes down to postulate a causal relation between A and B) (*APo*. I.4, 73b6–17).

Obviously, this is one of the important points at which metaphysics enters the theory of science.[12] Understanding the necessity of demonstrative premises and definitions

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12.   Another such point is the metaphysical argument in *APo*. I.22 that is designed to show that every scientific analysis must come to an end, i.e., that the sequences of ordered deductions and demonstrations must be finite and that, therefore, scientific principles exist.

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as being founded on essential relations in the metaphysical sense does *not* have dramatic epistemological implications, though. In particular, it does *not* imply that demonstrative premises are epistemologically certain; rather, they are, *if true at all,* metaphysically necessary and necessarily true, which is consistent with assuming that it might turn out that they are false. If syllogistic propositions are, according to the criteria provided by the theory of science, definitions or highest immediate explanatory premises in an actually constructed theory, then this is a good reason to assume that these premises are metaphysically necessary and represent essential relations. Therefore, the necessity of demonstrative premises does not follow from the necessity of the conclusion, but from the very notion of a successful demonstration (see *APo.* I.6, 74b5–17).

This has a rather interesting impact for Aristotle's concept of essences. The traditional simple view is that the essence of a thing (for instance, of a species) can be captured by one immediate defining formula pointing to a single unified cause of other properties of the thing. But it seems clear that in many cases just one definition does not have the explanatory power to demonstrate the properties of the thing in question. We need a lot more immediate *and* demonstrated premises within the demonstrative net in order to actually complete the explanations. In these cases, then, the essence of a thing is itself a complex matter (see Charles, 1997; Detel, 1997; Gotthelf, 1997).

Science and Dialectic

In the very first sentence of his *Rhetoric,* Aristotle proposes to distinguish both rhetoric and dialectic from science. Indeed, Aristotle conceives of dialectic as an art of reasoning that includes the capability of discussing *any* problem from *any* domain that we may come across (*Top.* I.1, 100a18–20). In many cases, the dialectician will examine both a given proposition and its negation, but typically he will not look for causes. All this does not go for science (*APo.* I.11, 77a31–35). Moreover, in examining, and trying to refute, a thesis put forward by an opponent, the dialectician may proceed from any assumption the opponent agrees with, without being obliged to care about the *truth* of the assumption (dialectic *ad hominem*) (*APr.* I.1, 24a22–b2). Hence, dialectical premises are not scientific premises. On this account, it seems that dialectic has nothing to do with science.

However, in the *Topics,* reasoning is defined as *dialectical* if it *reasons from noted beliefs* (*endoxa*) that are "things which are accepted by everyone or by most people; or by the wise – either by all of them, or by most, or by the most famous and distinguished" (*Top.* I.1, 100b21–23). This is, obviously, not dialectic ad hominem, but *dialectic proper*: a method of reasoning that relies exclusively on types of testimony which anyone has access to. Aristotle thinks that a proper dialectical examination can sometimes be helpful for finding out about the truth (*Top.* I.2, 101a35–37). Consequently, Aristotle himself argues often dialectically in a quite explicit way, not only in his ethical works, but also in the *Physics* (see his comment at *Cael.* III.4, 303a20–24) and, interestingly, also in the second book of the *Posterior Analytics,* where he devotes five chapters in a row to working through the problems concerning the relation of definitions and demonstrations (*APo.* II.3–7). Some scholars even argue that for Aristotle dialectic

proper is, in ethics as well as in physics, *sufficient* for reaching the principles (Owen, 1961). This is certainly an exaggeration (Bolton, 1987). Aristotle does feel, though, that dialectical reasoning proper is sometimes *necessary* for scientific work. It can often provide a more precise and adequate interpretation of given proposals and in this way set the stage for developing *scientific* answers for the problems that have been dialectically worked through (*Top.* I.2, 101a37–b4; *Phys.* IV.4, 211a7–11). Thus, the dialectical reasoning in *APo.* II.3–7 clearly sets the stage for determining, in a satisfying way, the exact relation between definitions and demonstrations (*APo.* II.8–10). It is in this sense that dialectic may even discuss the principles of science (*Top.* I.2, 101a37–b4). On this view, there seems to be an important connection between dialectic and science.

We should not conclude from this evidence, though, that Aristotle's account of the relation between dialectic and science is inconsistent. Clearly, dialectical reasoning may be sometimes helpful for, but remains different in method from, science. The adequate way of establishing scientific principles and in particular scientific definitions cannot be provided by dialectic (Bolton, 1987). But since in many cases what all people believe is true and what nobody believes is false (*EN* X.2, 1173a1–2; *Met.* α.1, 993a30–b4), scientists should see to it that the beliefs of experts and of most of the other people remain consistent (*Top.* I.10, 104a5–13) and that as many widely accepted beliefs as possible be proved to be true (*EN* VII.1, 1145b3–7). It is in this way that *science* is, on Aristotle's view, *closely connected to common sense and dialectical premises.*

There is a striking specific application of this view in the *Posterior Analytics*. Nominal definitions, being propositions that a specific scientific theory may try to demonstrate, are sometimes called "general" (*logikoi*) propositions that most people believe to be true. This indicates that Aristotle takes them to be dialectical starting points of scientific reasoning. More importantly, in trying to find adequate premises that we can use to demonstrate dialectical nominal definitions Aristotle points to accepted background theories that render the major term of the given nominal definitions more precise, thereby providing, at the same time, the theoretical framework that all possible demonstrations have to fit with. For instance, the claim that thunder is a certain noise in the clouds is a nominal dialectical definition. But for this definition to become a scientific theorem that may be demonstrated, we have to fill in the background theory of noises (cf. *De An.* II.6, II.8; *Cael.* II.9) that provides the scientists with a precise interpretation of the major term *noise*. Any demonstration that explains why thunder is a certain noise in the clouds has to be consistent with this background theory. If such a demonstration can be established, it shows, how *and* under which interpretation the nominal definition can be demonstrated (*APo.* II.8). This is a model of the way science is supposed to show why, *and* under which interpretation, beliefs accepted by most people are true.

Fallibility

Aristotle was certainly convinced that it is not impossible for human beings to grasp the truth, even in complex scientific inquiries; in this sense, he was not a skeptic. But

at the same time he emphasizes that "it is difficult to be aware whether one knows or not" (*APo*. I.9, 76a26), for "as the eyes of bats are to the blaze of day, so is the reason in our soul to the things which are by nature most evident of all" (*Met.* α.1, 993b9–11). Consequently, Aristotle feels that in our struggle to offer adequate scientific explanations, a lot of things can go wrong, and sometimes we cannot decide once and for all whether something went wrong. As already indicated, the simplest case in question is the attempt to establish a universal fact, say AaB. This is true only as long as we do not find a thing that is B, but not A. Furthermore, in trying to find, by way of a bottom-up analysis, immediate premises, how can we make sure that we have found premises that are truly immediate? In discussing how scientific theories may increase Aristotle talks about the discovery of new facts that may force us to extend the highest premises of our theory (*APo*. I.12, 78a14–22). Obviously, he takes into account that we may, at every stage of our scientific research, discover new facts; it follows that we can never make sure that we have found immediate premises because the discovery of new facts may point to new middle terms that enable us to demonstrate propositions we took before to be immediate. This is why Aristotle justifies his claim that "it is difficult to be aware whether one knows or not" by remarking: "For it is difficult to be aware whether we know from the principles of a thing or not – and that is what knowing is" (*APo*. I.9, 76a26–30).

Aristotle looks also at logical ways to refute given universal propositions. For instance, he examines in which way *ignorance*, i.e., *error through deduction*, comes about (*APo*. I.16–17). In this context, he envisages situations in which valid deductions entail false conclusions, in particular conclusions that are inconsistent with other universal propositions assumed to be true. In such cases we have, as Aristotle correctly remarks, to determine which of the premises are false. So there is sufficient evidence that Aristotle is talking about different ways of examining the truth-value of given scientific propositions by looking at their logical implications. Indeed, this is something Aristotle himself does several times in his own scientific works (see, e.g., *Cael*. II.13, 293a23–30; II.14, 297a2–6; III.7, 306a5–17; *Met*. Λ.8, 1073b32–1074a6).

There are a number of other ways our scientific research can fail. Thus, we may be inclined to demonstrate in a circular manner (*APo*. I.3); we may be, in determining scientific principles, satisfied with stating their truth or even their plausibility (*APo*. I.6); we may sometimes cross, within a sequence of demonstrations, the specific domain of a departmental science (*APo*. I.7); sometimes scientists raise unscientific questions (*APo*. I.12), and sometimes they don't use perception and induction at all, or take them to be sufficient for doing science (*APo*. I.18). Some scientists think they can get definitions without constructing demonstrations (*APo*. II.3–7), and some think that the Platonic method of dividing concepts is logically valid (*APo*. II.5); some take it that there is, for every explainable fact, a simple and unique demonstration, and some take it that there are, for every explainable fact, two or more demonstrations (*APo*. II.16–18). For Aristotle, all these assumptions or inclinations are methodological mistakes that are often not easy to detect. In sum, Aristotle does reflect in different respects on our weak epistemic condition, and he takes many scientific proposals and explanations, at every point of our scientific research, to be rather fragile and fallible (Detel, 1993).

Applicability

Ancient biology and geometry do not seem to argue in a syllogistic way, and it seems hard to see how they could do so. Neither does Aristotle himself, in his own biological works, seem to follow the methodological rules he recommends in the *Analytics*. This is the application problem. Recent work on Aristotle's biology indicates, though, that on a closer look he in fact does use a great number of rules proposed in the *Analytics*; in particular, he seems to assume that his arguments *can* at least rather easily be reconstructed in a formal syllogistic way, and it has been shown that such reconstructions can actually be offered (Bolton, 1987; Detel, 1997; Freeland, 1990; Gotthelf, 1987a, 1997; Lennox, 1987; McKirahan, 1995; and in this volume Lennox, ARISTOTLE'S BIOLOGY; see however Modrak, 1996). In general terms, in reading Aristotle's logic and theory of science we should proceed from the assumption that there is a *conceptual unity* of these disciplines with his metaphysics and his empirical studies like biology or meteorology (Pellegrin, 1986, p. 50).

The case of geometry proves to be a lot harder. One of the main problems is that Euclidean proofs use two-placed predicates that cannot easily be symbolized syllogistically. Nevertheless, there is evidence that Aristotle himself *thought* that syllogistic is applicable to geometry, too (*APo*. II.11, 94a20–35). Of course, the easiest way of dealing with this claim is simply to declare it trivially wrong, and that is indeed what most scholars are inclined to do. But if we look more closely at the examples Aristotle hints at we can see that there may be a way out of this problem: these examples suggest that a syllogistic symbolization of geometrical proof is supposed to be extremely general, such that the entire idea of the proof is contained in the middle term of the demonstration (Detel, 1993, vol. 1, pp. 172–81; Mendell, 1998).

In any case, Aristotle's crucial idea is that formal logic must be an essential part of a theory of science that is supposed to provide the foundation for rationally reconstructing scientific practice; and this idea proved to be extremely influential and fruitful throughout the history of science, although syllogistic turned out to be too restricted in scope to support this idea sufficiently.

Readings of Aristotle's Theory of Science

The first principles of science in the *Analytics* have been thought, by centuries of commentators, to be something like a priori truths grasped by special acts of intellectual insight that guarantee the epistemic certainty of the principles.[13] And, so the story goes on, once we have grasped the principles we can try to deduce, or to demonstrate, further theorems in a top-down procedure that guarantees, because of the logical validity of our deductions, the truth of all the theorems too. This traditional outline of Aristotle's idea of science and scientific activity can be called the *axiomatic reading*. Indeed, Aristotle tells us that knowledge and insight are epistemic states "by which we

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13.   For literature on this point see Detel, 1998, pp. 157–8, n. 2.

grasp the truth" and so are "always true" (*APo.* II.19, 100b6–8). He stresses that we must be more aware of, and more convinced by, the principles of science than by their conclusions (*APo.* I.2, 72a15–b4), and that these principles must somehow be assumed, although they cannot be proved or demonstrated (*APo.* I.2). And an appropriate scientific theory is supposed to rely, of course, on methods and proposals that avoid all the methodological mistakes that are marked so explicitly by Aristotle. These and similar remarks have been taken to confirm the axiomatic reading of the *Analytics*.

Recently scholars have suggested an alternative interpretation: "There are hints that the theory of the *Posterior Analytics* was meant to provide the proper formal account and presentation of the finished system" (Barnes, 1975, p. x; see also Barnes, 1969, 1981; and Bauman, 1998). According to this picture, it is extremely important not to confuse the aspect of discovery and scientific research, on the one hand, and the aspect of learning, teaching, and presenting an established scientific theory, on the other hand. Discovery and research use induction and empirical investigation, and they look primarily at *phenomena*, i.e., at what most people think to be true (see Owen, 1961; Wieland, 1962). Essences of things are nothing else than the set of properties that turn out, in our scientific research, to be causally basic properties of these things; and "insight" as a mode of discovery is absent from the *Posterior Analytics*. From the point of view of this *pedagogical reading* of the *Analytics*, Aristotle seems to be a "whole-hearted empiricist" (Barnes, 1975, p. 259). Influential scholars see the pedagogical reading as "the new orthodoxy and the now accepted interpretation of the *Posterior Analytics*" (Bolton, 1987, p. 121; Sorabji, 1980, pp. 188, 194).

Finally, some scholars have emphasized that Aristotle sees our scientific activity as aiming, not at the production of entirely new discoveries, but rather at *deepening given knowledge* by providing explanations of well-known phenomena. This is why questions of justification are almost absent from the *Posterior Analytics* (Burnyeat, 1981; Kosman, 1973; Lear, 1988; Lesher, 1973): Our given knowledge is not *justified* by explanations and demonstrations; rather, explanations and demonstrations *deepen* our given knowledge and help us to *better understand* phenomena that we already take to be the case.

There is a nice little remark Aristotle makes about hitting the truth: "no one is able to attain the truth adequately, while every one says something true about the nature of things" (*Met.* α.1, 993a31–b4). This applies also to the three interpretations of his theory of science just outlined. The beginning of wisdom in reading the *Analytics* consists in distinguishing descriptions of an *ideal of science and scientific activity* that shows what a *perfect scientific theory* should look like, and descriptions of the *epistemic condition human researchers are in* at every moment of their scientific activity and career. It is precisely by developing a perfect ideal of science that one can indicate in which way we may fail in doing science and in which respect we can never make sure once and for all that we have achieved perfect scientific knowledge. In his theory of science we can see Aristotle doing *both* things: sketching what perfect scientific knowledge comes down to, *and* indicating in which way our human epistemic condition is fragile and fallible. For only by doing both these things can we *improve* our fragile epistemic condition and come *closer* to perfect knowledge. This is the basic assumption of a *complex reading* of the *Analytics* (Detel, 1998, pp. 176–7).

From this point of view the axiomatic reading focuses exclusively on Aristotle's ideal of knowledge. Claiming that knowledge and insight are always true is a proposal about

what perfect knowledge and insight perfected by analysis should be: if it is *really* perfect knowledge, it is, and remains, true. That is how we define perfect knowledge. But the crucial flaw of this reading is to take Aristotle's thoughts about perfect science to cover the epistemic condition of human scientific research too.

The pedagogical reading, on the other hand, correctly emphasizes that Aristotle talks, for instance, in the very first sentence of the *Posterior Analytics,* about the context of teaching and learning that every adequate scientific theory belongs to. It is also true that Aristotle seems to think that teaching and learning a scientific theory requires presenting the theory in a deductive and demonstrative frame so that the student can see how its proposals depend on each other. But it is clearly wrong to suggest, as the pedagogical reading has it, that there is a sharp methodological distinction between perception, induction, and dialectical reasoning as belonging to the context of discovery, and deduction and demonstration as belonging to the context of teaching, learning, and presenting the theory. This is obviously inconsistent with Aristotle's claim, so decisive for his view of science, that scientific activities aim primarily at the discovery of causes; the discovery of causes and highest premises, however, necessarily requires the construction of demonstrations. Therefore, deductions and demonstrations belong to the context of discovery too.

Finally, it is true that Aristotle is, in the *Analytics,* mainly interested, not in the knowledge of facts, but in the knowledge of causes of given facts that deepen our knowledge of facts simply by explaining them causally. But we should not overlook that Aristotle does reflect, even in the *Analytics,* also on methods of establishing facts, and that, in general, questions of justification are by no means completely absent from the *Analytics.* This holds even for scientific principles. Aristotle certainly thinks that scientific principles are *given* in the restricted sense that they cannot be *proved* or *demonstrated.* But *postulates* and *suppositions* can be *justified* in logic and first philosophy. Thus, Aristotle himself justifies, for instance, the law of the excluded middle in the *Metaphysics* (Book Γ) and the validity of syllogistic inferences in the *Prior Analytics* (Book I). Likewise, it is the job of first philosophy to justify existence claims about fundamental entities of scientific domains, as Aristotle demonstrates too, for instance, in the case of mathematical entities (*Metaphysics* M). Finally, *definitions* in the sense of highest explanatory principles and demonstrative premises cannot be *demonstrated* or *proved* either, but at the same time there is a clear double sense in which they can be *justified* even within the departmental science they belong to: as universal propositions, they can and must be justified by induction or deduction (*APo.* II.19), and as immediate explanatory premises they must be justified by showing that they sit at the top of actually constructed analyses and sets of demonstrations making up a whole scientific theory.

One way of characterizing the *complex reading* of Aristotle's theory of science is to say that Aristotle conceived of science, and of scientific activity, as an *epistemic culture.* In general, a *culture* is a *set of practices* that are based *on shared background assumptions* and are taught and learnt; in particular, an *epistemic* culture consists of practices that are designed to evaluate claims to knowledge and to produce justified knowledge; at the same time, an epistemic culture relies specifically on shared background assumptions about what perfect knowledge is, and its methods and results are transmitted by teaching and learning them. Outlining the complex reading this way makes clear that

it preserves the advantages of the three other readings sketched above while at the same time avoiding their narrowness.

Epistemological Status of the *Analytics*

In Aristotle's classification of all sciences (*Met.* E.1) dialectic, logic, and theory of science are missing. Aristotle does not seem to count them among the sciences. This has provoked a debate among scholars (e.g., Ackrill, 1981, p. 79; Barnes, 1982, p. 25; Ross, 1923, p. 20). The suggestion offered by the Aristotelian *tradition* is that Aristotle considered these disciplines as mere *tools* of the sciences. But Aristotle himself gives us some clues that help to understand better how he looked at the status of logic, dialectic, and the theory of science.

Specific sciences proper are defined by the specific domain, or *genus* (*genos*), they deal with. Genera are, in Aristotle's view, radically different from each other: they "have no path to one another, but are too distant and without common measure" (*Met.* I.4, 1055a6–7). Different genera are therefore separated from each other in such a way that the gap between them is, at least in any direct way, impassable (though there may be analogies between them). At the same time, any genus is a space of specific differences and includes contrary kinds (*eidē*), the relation of contrariety being defined, by a theory of opposites, as the maximum difference between attributes such that contrary attributes cannot coexist in the same subject in the same relation (*Met.* I.4). Every specific science can, therefore, be defined *uniquely* by its specific genus, and it explores the contrary kinds of its specific domain. The notions of a genus (*genos*) and a kind (*eidos*) are not, however, taxonomic concepts in the modern sense of genus and species. In his biology, for instance, Aristotle applies the term *genos* often to things that count as species in the modern taxonomic sense. Animal classifications are, in Aristotle's view, outside science, the central project of Aristotle's biology being what we might call an etiological moriology (Balme, 1962; Pellegrin, 1986). It is on the basis of the radical separation of scientific genera from each other that Aristotle insists that scientists are not permitted to cross over, in their explanations and demonstrations, from one genus to another (*APo.* I.7).

Aristotle's theory of science is, therefore, a variety of an *anti-reductionist scientific pluralism* that puts emphasis on the *specificity* and *uniqueness* of domains and terminologies that are constitutive for every specific science (although there are cases of subordination of one science to another within the same genus; for example, optics is subordinate to geometry). There are indications that Aristotle conceived of scientific genera as being *abstracted* from natural things by scientific activity. Thus, for example, part of establishing the science of biology is that scientists look at natural things *qua* living things, and part of establishing the science of geometry is that scientists look at natural things *qua* dimensional entities (*Met.* M.3, 1077b17–1078a26; *Phys.* II.2, 193b31–194a12). This is not to say that Aristotle entertains an anti-realistic position about scientific genera; rather, he feels that natural things are bearers of a great variety of structures and can therefore be looked at in different ways. It is up to the scientist what kind of structure he wants to look at, thereby abstracting from other parameters that are also given in natural things.

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In any case, logic and the theory of science do not explore a specific domain; for "neither of them deals with the nature of any definite subject, but they are mere faculties of furnishing arguments."[14] In addition, logic and the theory of science do not seem to be looking for *causes* either. In these crucial respects they differ, like dialectic, from sciences proper.

More importantly, recognizing and following general *methodological* rules is a matter, not of science, but of *education*. Thus, the wrong demand that everything should be demonstrated (discussed in some detail in *APo.* I.3) is due to "want of education, for not to know of what things one may demand demonstration, and of what one may not, argues simply want of education" (*Met.* Γ.4, 1006a5–8). Likewise, it is "the mark of an educated man to look for precision in each class of things just so far as the nature of the subjects admits" (*EN* I.3, 1094b24–25). In general, concerning every study and investigation, there are, according to Aristotle, two different kinds of proficiency: one is a kind of acquaintance with the subject, provided by sciences proper; the other is what "may be properly called educated knowledge of the subject. For an educated man should be able to form a fair judgment as to the goodness or badness of an exposition in nearly all branches of knowledge, and not merely in some special subject." Therefore in the sciences, in particular in the natural sciences, "there must be certain canons, by reference to which a hearer shall be able to criticize the method of a professed exposition, quite independently of the question whether the statements made be true or false." Indeed, in general "to be educated is to do this, and the man of general education we take to be such" (*PA* I.1, 639a1–15) (George, 1993). These illuminating remarks show how Aristotle conceives of the true status of logic and a theory of science: learning and mastering these disciplines is, not to be a scientist, *but to be educated in the most general sense*; logic and theory of science are the very core of *paideia*. One important aspect of this general education is a *rational critical attitude* towards the *structure* and *validity* of proposed arguments. To use modern terminology, to be educated in this general sense, i.e., to use logic and scientific methodology in a critical and rational way, is to *move in the space of reason, to participate in the game of giving and asking for reasons*. The process of learning logic and scientific methodology is *to tame nature and to move from the realm of nature into the space of reasons*, and this is one of the most important *conditions for living a good life*. It is in this way that Aristotle lucidly and admirably shows us the true status, and the true importance, of the formal disciplines that he himself has the eternal merit of having invented.

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14. See *Rh.* I.2, 1356a32–33. This remark is restricted to rhetoric and dialectic, though; but since syllogistic inference rules belong also to dialectic (*APr.* I.1, 24a26–28), this goes also for syllogistic logic, and therefore a fortiori also for the rules of scientific arguments developed in the *Posterior Analytics*.

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