What Keeps the Earth in Its Place? The Concept of Stability in Plato and Aristotle

GIORA HON* AND BERNARD R. GOLDSTEIN**

Abstract. Symmetry as it is applied today is a modern concept; hence it is implausible to ascribe this concept to classical thinkers such as Plato and Aristotle. How then should one interpret discussions in antiquity on the stability of the Earth? In this paper we analyze the arguments in order to see how they 'work'. While both Plato and Aristotle invoked the concept of likeness, Plato also depended on the concept of equal balance, whereas Aristotle depended on the concept of natural place. But in neither case did they appeal to symmetry.

Keywords. Aristotle, equilibrium, Plato, stability of the Earth, symmetry

Nothing is more remarkable than the stability... of the world.
Cicero, *De natura deorum*, II.115.

1. Introduction

On several occasions ancient philosophers sought to explain the perceived stability of the Earth. Plato (*ca*. 427–347 BC) and Aristotle (384–322 BC) put forward intriguing arguments which are now commonly understood to be based on symmetry considerations. Since symmetry (as we apply it today) is a modern concept, more precisely, a 19th century concept, we find it implausible to ascribe to Plato and Aristotle such a conception (see Hon and Goldstein, 2008). But, then, the question arises, how should one interpret these ancient texts? In this paper we analyze the arguments closely, unpacking them, as it were, in order to see how they 'work'. We submit that Plato and Aristotle developed categorically different kinds of arguments to explain the perceived stability of the Earth. While both invoked the concept of likeness, Plato also depended on the concept of equal balance, whereas Aristotle depended on the concept of natural place. But in neither case did they appeal to symmetry.

*Department of Philosophy, University of Haifa, Haifa 31905, Israel. E-mail: hon@research.haifa.ac.il
**School of Arts and Sciences, University of Pittsburgh, 2604 Cathedral of Learning, Pittsburgh, Pennsylvania 15260, USA. E-mail: brg@pitt.edu

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2. Arguments for Stability in Plato and Aristotle

After a discussion in the *Phaedo* on the immortality of the soul and how souls migrate from the Earth to the underworld, Socrates informs Simmias—one of the interlocutors of the dialogue—that there are many strange places in the world and that the Earth is unlike what people believe it to be in nature or size. Intrigued, Simmias demands an example. Socrates responds by distinguishing between reporting and proving, and proceeds to develop the following argument in the form of a proof:

> 'I have been persuaded', said Socrates, 'first that if the earth is round and is in the center of the heaven, it has no need of air in order not to fall, or of any other such necessitation [*anankês*], but that all that is needed to hold it there is the heaven's likeness [*homoiotêta*] to itself all round and the earth's own equal balance [*isorropian*]. For something equally balanced, placed at the center of some like thing [*homoiou*], will not be able to incline [*klithênai*] more or less in any direction, but thanks to its condition of likeness [*homoiôs*] will remain without inclination [*aklines*]...' (Plato, *Phaedo*, 108e4-109a6; Sedley, 1989, p. 363).

We have chosen Sedley's translation since he adheres closely to the original Greek and renders the key terms consistently. We emphasize that we are interested solely in the structure of the argument and not in its role in the *Phaedo*. But, before we discuss Plato's argument, a general methodological observation is in order.

From a methodological point of view, there is no escaping the issue of interpretation. Even if one wishes to focus only on the structure of the argument (as we do), one still needs to pay close attention to the original wording. For reasons which will become clear later in this article, Plato does not apply the Greek term, *summetria*, in the passage under consideration. So what then is the nature of this argument? To respond to this question effectively two distinct steps are required in the following order: (1) a close reading of the text with special attention to its wording, and (2) a minimal interpretation. To keep the flow of the analysis, we proceed directly to discuss the argument, postponing our assessment of various translations of this passage—and a few related ones—to the next section.

Two key concepts are involved in setting up Plato's argument, 'likeness' [*homoiotês*] and 'equal balance' [*isorropia*] but, as we have indicated (following Sedley), describing the argument is highly dependent on the interpretation of the passage; that is, one has to be 'very careful in considering precisely what is meant to be explaining what' (Sedley, 1989, p. 363). We discern a complex argument that is based on five claims, presented in two separate parts of the passage. In the first part we have three: (1) the Earth is spherical in shape, (2) it is located in the center with respect to the heaven, and (3) the 'air', or any other 'stuff' between the Earth and the heaven, is irrelevant to the issue of stability. Plato puts forward two more claims in the second part of the argument: (4) the parts of the heaven are uniform, that is, they share the property of likeness such that its parts cannot be distinguished from one another, and (5) the Earth is equally balanced. Plato then brings the argument together, namely, declaring that which is equally balanced around its center and uniform 'will not incline any way..., but will always remain in the same state and not deviate' (Jowett's translation in Eliot, 1909, p. 105). The stability of the Earth, i.e. that it has no movement as a whole, then follows as a conclusion.

How are we to understand the argument that leads from the five claims to the conclusion of stability? The argument proceeds in two steps, corresponding to the two parts. Plato states without argument that (3) there is no need for air, or any other 'stuff', to keep the Earth from falling. The first two claims, namely, that (1) the Earth is round, and that (2) it is placed at the center of the heaven which, in turn, is assumed to be (4) undifferentiated in substance, together with the claim that (5) the Earth is equally balanced, are all consistent with claim (3). In other words, the five claims constitute a consistent set. It is noteworthy that claims (1) and (2) of the first part are geometrical while the remaining three are physical.

The object of this first part of the argument is Plato's criticism of theories of matter that had been put forward to explain the stability of the Earth. Plato is in fact engaged in a polemic against some unnamed contemporaries. Many of the details of this polemic can be reconstructed from passages in Plato and Aristotle. For example, preceding the passage under discussion in Plato's *Phaedo* is the following:

> ... one man makes the earth stay below the heavens by putting a vortex about it, and another regards the earth as a flat trough supported on a foundation of air; but they do not look for the power which causes things to be now placed as it is best for them to be placed, nor do they think it has any divine force, but they think they can find a new Atlas more powerful and more immortal and more all-embracing than this, and in truth they give no thought to the good, which must embrace and hold together all things (Plato, *Phaedo*, 99b-c; Fowler, [1914] 1933, p. 341).

The polemical tone is evident but, more to the point, Plato is not content with theories that appeal either to a vortex or to air in explaining stability. He does not mention the theorists by name, but in *De caelo* Aristotle provides much background concerning the views of the philosophers that Plato probably had in mind.

As we have seen, Plato introduces several claims (stated without proof): (1) the Earth is round, and (2) at the center of the heaven. Claim (2) also suggests that the heaven is spherical, although it is merely implied. Claim (3) states that, contrary to the views of his predecessors, Plato thinks the 'stuff' between the Earth and heaven is irrelevant to its stability. In contrast to the views of Plato, Aristotle informs us that Anaximenes (*ca.* 585–525 BC), Anaxagoras (*ca.* 500–428 BC) and Democritus (*ca.* 460–370 BC) believed that the flatness of the Earth is the cause of it remaining at rest as it 'sits' on air beneath it. He adds that some like Thales (*ca.* 624–546 BC) believed that the 'stuff' is water, rather than air (Aristotle, *De caelo*, ii.13, 294a30 and 294b14–23; Stocks, 1922). Aristotle also records (295a9–25) the theory of Empedocles (*ca.* 490–430 BC) with 'whirls' (cf. Sedley, 1989, p. 363). This brings the negative aspect of Plato's argument—part one—to an end.

If no 'stuff' is involved, then what is the source of stability? Note that stability is a physical state, and so the argument must include physical claims—geometry alone will not suffice. This is the subject of the positive, and physical, aspect of the argument—part two. Stability is understood as the net result of opposing inclinations that cancel one another—the inclinations being equal in opposite directions. Plato's aim is to establish a set of physical conditions which entails stability, that is, the cancellation of inclinations. Thus, in part two a physical claim has to be made about the Earth, that is, the Earth is equally balanced, in addition to being situated in the center of the heaven. The likeness of the heaven together with the equal balance of the Earth with respect to its center are the required physical conditions from which it follows that the Earth is in a stable state—any tendency to move in one direction will be canceled by an equal tendency in the opposite direction. In fact, Plato stipulates the condition for the Earth to be equally balanced, namely, it too has the property of likeness. In Jowett's translation, 'that which, being in equipoise, is in the centre of that which is equably diffused, will not incline any way in any degree' (Jowett, in Eliot, 1909, p. 105).

Stability then follows from the two physical claims of part two: (4) the likeness of the heaven in substance, and (5) the equal balance of the Earth, against the geometrical background of part one which stipulates that the Earth is spherical and situated at the center of the heaven. The passage ends with a definition of 'equally balanced', namely, any inclination in one direction is canceled by an equal inclination in the opposite direction. We thus take 'equal balance' to mean 'equal tendencies to be moved in opposite directions'. Notice that the 'thing' in balance has to be specified, in this case it is the 'tendency to move' (or 'to incline').

In another passage, relevant to the previous argument, where the context is a discussion of opposite pairs such as 'hot' and 'cold', 'hard' and 'soft', Plato also inquires into the common distinction, 'above' and 'below'. The view that the heaven is spherical is implied in the passage in the *Phaedo*, and the following passage in the *Timaeus* is consistent with it. Thus, all the extremities, i.e. the parts of the heaven, are equally distant from the center where Earth is situated. Consider now an observer on Earth:

> Seeing... that the Cosmos is actually of this nature, which of the bodies mentioned can one set 'above' or 'below' without incurring justly the charge of applying a wholly unsuitable name? For its central region cannot rightly be termed either 'above' or 'below', but just 'central'; while its circumference neither is central nor has it any one part more divergent than another from the centre or any of its opposite parts. But to that which is in all ways uniform [*homoiôs*], what opposite names can we suppose are rightly applicable, or in what sense? For suppose there were a solid body evenly-balanced [*isopales*] at the centre of the Universe, it would never be carried to any of the extremities because of their uniformity [*homoiotêta*] in all respects; nay, even were a man to travel round it in a circle he would often call the same part of it both 'above' and 'below', according as he stood now at one pole, now at the opposite. For seeing that the Whole is, as we said just now, spherical, the assertion that it has one region 'above' and one 'below' does not become a man of sense (Plato, *Timaeus*, 62c–63a; Bury, [1929] 1975, p. 159; cf. Cornford, [1937] 1966, pp. 262–263; for extensive discussion, see O'Brien, 1984, pp. 3–27).

We note Plato's ingenuity: he describes the cosmos as having the properties of a (finite) sphere, whose central region refers to the Earth, an equally balanced solid body. What is the argument here? What allows us to move from the claims to the conclusion, namely, that there is no preferred direction?

We discern two separate claims in Plato's argument in this passage in the *Timaeus*: (1) the heaven is a sphere whose parts are all alike (i.e. its parts are indistinguishable from one another) with the Earth at its center; and (2) the Earth is an equally balanced solid sphere whose center is located at the center of the heaven. On the basis of these two claims, Plato drew the conclusion that there is no proper use of the pair of contraries, 'above' and 'below', with respect to any region of the 'Whole'. Claim (1) implies that we cannot make any distinctions (with respect to direction) based on the heaven, for its parts are all alike; claim (2) tells us that we cannot make any such distinction based on a property of the Earth, for it is equally balanced. Hence the combined system, Earth and heaven, is undifferentiated, and the pair of contraries, 'above' and 'below' loses its meaning.

Plato's conclusion differs from Aristotle's view whose concept of natural place determines spatial directionality. Aristotle remarks:

> There are certain things whose nature it is always to move away from the centre, and others always towards the centre. The first I speak of as moving upwards, the second downwards. Some deny that there is an *up* or *down* in the world, but this is unreasonable. There is no up or down, they say, because it is uniform [*homoios*] in all directions, and anyone who walked round the earth would everywhere be standing at his own antipodes. We however apply *up* to the extremity of the world, which is both uppermost in position and primary in nature; and since the world has both an extremity and a centre, there clearly must be an *up* and *down* (Aristotle, *De caelo*, iv.1 308a15 ff; Guthrie, 1939, p. 329).

Aristotle does not name those theoreticians who hold the view contrary to his claim that there is an *up* and *down* in the world but, evidently, he is alluding to Plato's *Timaeus* (as Guthrie notes, this passage alludes to *Timaeus* 62d-63a).

In contrast to Aristotle, Plato's argument is based on both concepts, likeness and equal balance. Plato uses 'likeness' for the property of the heavenly sphere and 'equally balanced' for the property of the Earth. As indicated, these two concepts refer to physical properties, whereas the claim that both the heaven and the Earth are spherical in shape refers to a geometrical property.

Another way to throw light on Plato's arguments for stability and directionality is to examine the opposite state—instability—as Plato portrays it in the *Timaeus*: what was the state of matter when chaos reigned? *Contrariorum eadem est scientia*: we never really know what a thing is unless we are also able to give a sufficient account of its opposite (Mill, [1843] 1941, Bk. V: 'On Fallacies', p. 481). The passages on which we have focused in the preceding discussions concern 'stability' after the Demiurge had fashioned the elements, and so the state of the world (and that of Earth) should be the opposite of what was the case in the chaotic state.

> Let this, then, be, according to my verdict, a reasoned account of the matter summarily stated,— that Being and Place and Becoming were existing, three distinct things, even before the Heaven came into existence; and that the Nurse of Becoming, being liquefied and ignited [Cornford, [1937] 1966, p. 198: '... being made watery and fiery...'] and receiving also the forms of earth and of air, and submitting to all the other affections which accompany these, exhibits every variety of appearance; but owing to being filled with potencies [*dunameôn*] that are neither similar [*homoiôn*]

> nor balanced [*isorropôn*], in no part of herself is she equally balanced [*isorropein*], but sways unevenly [*anômalôs*] in every part, and is herself shaken by these forms and shakes them in turn as she is moved. And the forms, as they are moved, fly continually in various directions and are dissipated; just as the particles that are shaken and winnowed by the sieves and other instruments used for the cleansing of corn fall in one place if they are solid and heavy,... (Plato, *Timaeus*, 52d-52e; Bury [1929] 1975, p. 125, slightly modified; cf. Cornford, [1937] 1966, p. 198 and, for comments, pp. 199ff.).

According to Plato, chaos is the state of the world before the Demiurge imposed order on it, and the stability of the Earth is one result of his action. So, in the state of chaos the 'potencies are neither similar nor balanced' and no part of the world is 'equally balanced'; therefore, it moves irregularly (i.e. lacking a pattern). In sum, there is no stability. If in the chaotic state 'potencies' were not equally balanced, it seems to follow that, after the act of fashioning the material world, the 'potencies' are equally balanced.

For the chaotic state Plato explicitly appeals to *dunameôn*, and one might think that this term is also to be understood implicitly in the passage in the *Phaedo* about the current stability of the world. But this is unwarranted: in fact, the state of balance is neutral with respect to the different kinds of phenomena that the balance controls. For example, the state of balance can refer to armies as well as to tendencies to motion. In other words, the 'thing' which is in balance has to be specified. Indeed, we see Plato specifying the qualities of the chaotic state: potencies are not in balance. This contrasts with the case in the passage from the *Phaedo* that we have cited, where the 'equally balanced' Earth is positioned at the center of 'likeness'. Juxtaposed with the passage in the *Phaedo*, this text in the *Timaeus* is most instructive: the author makes use of the same terms in the context of contrary states. The consistent usages of the key terms give us confidence that our understanding is correct.

We now turn to Aristotle's explanation of the phenomenon of stability. The subject of Aristotle's *De caelo*, ii.13, is whether the Earth is at rest or in motion, the very issue that Plato addressed. Indeed, Aristotle refers to Plato's *Timaeus* explicitly.[1] In the course of his discussion, Aristotle comments on an argument he ascribes to Anaximander (*ca.* 610–546 BC).

> There are some people, such as Anaximander among the earlier thinkers, who say it [the Earth] remains at rest because of uniformity [*homoiotêta*], since it is no more suitable for what is situated at the centre and uniformly [*homoiôs*] related to the extremities to be borne upward than downward or to the side; but it is impossible to move in opposite directions simultaneously, so that necessarily it remains at rest. This is said cleverly but not truly,... (Aristotle, *De caelo* ii.13, 295b10 ff.; Mueller, 2005, p. 74, slightly modified, based on the translation in Kirk and Raven, [1957] 1966, p. 134).

In describing Anaximander's argument, Aristotle uses a key term which we have just seen in the *Phaedo* 108e ff., namely, *homoiotês*. The adverb, *homoiôs,* is another related word used by Aristotle in this argument that also appears in Plato's *Phaedo*. We note further that there is no occurrence of *isorropia* or *isopalês* in Aristotle's report of Anaximander's argument.[2]

As we have done in the case of Plato, we limit discussion of interpretative issues and concentrate on the structure of the argument. In Plato the two concepts, 'likeness' and 'equal balance', are distinct, and Plato then combines them in the argument for stability. Although, in his description of Anaximander's argument, Aristotle appeals to the same concept that Plato applied, namely, 'likeness' (here translated, 'uniformity'), he joins it—on behalf of Anaximander—with the centrality of the Earth, and does not explicitly invoke Plato's claim of 'equal balance'. That is, Anaximander (according to Aristotle) does not have a special term for 'equal balance'.

Furthermore, in this formulation Anaximander does not refer to the 'heaven'. Still, calling the Earth 'central' probably means central with respect to the heaven. The universe is finite; hence a line drawn from the center of the Earth reaches the extremity of the universe. Thus, the 'extremities' almost certainly allude to the heaven. The argument then has two different claims, namely, 'the Earth is situated at the center' and 'it is uniformly related to the extremities'; the former is geometrical while the latter is physical. The first claim has to do with the relation of the Earth to itself, and the second its relation to the heaven. To say that the Earth is at the center of the heaven is not sufficient for claiming that it is uniformly related to all parts of the heaven.[3] Note the similar usage of 'extremities' in Plato's argument in the *Timaeus* (62c–63a): 'For suppose there were a solid body evenly-balanced [*isopales*] at the center of the universe, it would never be carried to any of the extremities because of their uniformity [*homoiotêta*] in all respects' (Bury, [1929] 1975, p. 159).

Anaximander's argument conveys the sense of *isorropia* as it was used by Plato, but without the term: the point is made by the allusion to tendencies to motion which cancel each other. It is then fair to say that the arguments of Plato and of Anaximander are essentially the same, but expressed differently. Indeed, as noted by Stocks, the recurrence of similar words suggests that 'Aristotle probably had the *Phaedo* in mind here'.[4]

However, in contrast to Stocks, we observe that although the structure of the arguments is similar, there are nuances in terminology. According to Aristotle, Anaximander attempted to explain the stability of the Earth (in the same sense as Plato did), based on two claims, namely, (1) the Earth is situated at the center and (2) the Earth is related uniformly (*homoiôs*) to the extremities. The argument is based on the concept of 'equal balance' without a specific term for it; that is, for Anaximander tendencies to motion (if there are any) are equally balanced, whereas for Plato the Earth itself is 'equally balanced'. Thus, Anaximander's argument 'works' as follows: either there is no tendency to motion or, if there were such tendencies, they would be equal in opposite directions and cancel each other. But Aristotle is not persuaded. In his view Anaximander failed to explain the Earth's stability; the argument is 'clever' but not 'true'. Aristotle thus rejects Anaximander's argument altogether and, presumably, Plato's as well. For Aristotle this kind of argument is not sensitive to the physics of the situation. He claims that certain phenomena need to be considered since they affect the argument for the Earth's stability: fire has a natural tendency to rise away from the center of the Earth, and heavy bodies have a natural tendency to fall towards the center of the Earth.

In fact, for Aristotle the stability of the Earth is based on a completely different set of reasons. He remarks:

> It is also strange to inquire why the earth remains at the centre, but not to inquire why fire remains at the extremity. For if the extremity is its place by nature, it is clear that it is necessary that there also be some place for earth by nature. But if its present position is not its [place] by nature but it remains there because of the necessity of uniformity [*homoiotêtos*], then they should inquire about the resting of fire at the extremities (Aristotle, *De caelo*, ii.13, 295b25 ff.; Mueller, 2005, p. 74; cf. Guthrie, 1939, p. 237).

Underlying Aristotle's position is his general theory which includes a doctrine of 'natural place': the heavy elements, earth and water, have a natural tendency to move toward the center of the cosmos which coincides with the center of the Earth, while the light elements, fire and air, have a natural tendency to rise to the extremity of the sublunary world, away from the center of the Earth.[5] For Aristotle natural motion towards (or away from) the center of the Earth only applies to the sublunary realm and this motion takes place along straight lines. By contrast, according to Aristotle, circular motion is the natural motion of the fifth element in the celestial realm.

Here we have just one claim and the principle of 'natural place' which situates the Earth at the center, thereby implying equal distances to every extreme point—without mentioning the heaven. Furthermore, Aristotle argues against those who claim that 'likeness' is a reason for stability; they have not taken into consideration the tendency of fire to rise, that is, how can one condition (likeness) account for two opposite effects, namely, (1) making heavy bodies fall, and (2) fire rise? Of course, given Aristotle's doctrine of natural place, this is not a problem.

We have discussed arguments by Plato and Anaximander (reported by Aristotle), and Aristotle's responses to them, all directed at demonstrating the perceived stability of the Earth. The concepts at the disposal of these philosophers were limited, but ingenious; foremost among these concepts were 'likeness', 'equal balance', and 'natural place'. It is most tempting for scholars to recast these arguments in ways that appeal to powerful modern concepts, and we turn to a critical examination of such analyses. We are particularly concerned with the extent to which various translations of ancient texts have misled contemporary philosophers of science.

3. The Burden of Translation

The first key term in Plato's argument for stability, *homoiotês*, is translated here as 'likeness', that is, the heaven is uniform throughout; it has the property of likeness or resemblance to itself. In other words, it is undifferentiated—it is like itself all round, it is uniform. We prefer 'likeness' to 'uniform', since the former rendition preserves the literal meaning while the latter contains an interpretation. We deliberately avoid 'homogeneity', found in several translations, because it would seem to imply a claim about constituent elements, which is unwarranted (see Fowler, [1914] 1933, p. 375; cf. Burnet, [1911] 1963, p. 128).

The second key term is *isorropia*; it is translated here as 'equal balance'.[6] To establish the basis for translating this term, we turn our attention to antecedents of Plato's usage, and begin by considering a passage in the *Histories* of Herodotus (*ca*. 484–425 BC):

> So the Lacedaemonians had taken possession of the oracles, and as they observed the Athenians growing in strength and by no means ready or willing to obey the Lacedaemonians, they recognized that in freedom, the Attic race would equally match [*isorropon*] their own, but that when repressed by tyranny, it would be weaker and willing to submit to the authority of others.[7]

The literal sense of *isorropon* in this context is equally matched armies, that is, neither side is able to dominate the other. According to Herodotus, the Lacedaemonians thought that, were the Athenians to remain a free people, their military would match that of the Lacedaemonians themselves.

In another domain, Vlastos drew attention to the methodology of Hippocratic medicine which makes a metaphorical use of this idea.

> If there is health, it is assumed that the constituent powers must be (1) in equilibrium and therefore (2) equal to one another, much as opposing parties in an evenly matched contest are assumed to be equal. This is exactly the sense in which equality figures in the medical treatises and, indeed,... in the whole development of early cosmological theory from Anaximander to Empedocles. Powers are equal if they can hold one another in check so that none can gain 'mastery' or 'supremacy' or, in Alcmaeon's term, 'monarchy' over the others (Vlastos, 1995, p. 59).

According to Vlastos, in the Hippocratic tradition the military metaphor is applied to the powers of the body that maintain health: they hold one another in check, that is, they are equally matched. Vlastos adds that the same military metaphor was applied in early Greek cosmology.

In his second argument, on the inappropriateness of the pair, 'up' and 'down', Plato invokes the term, *isopalês*, in the same sense that he used *isorropia* in the *Phaedo*, that is, 'equally balanced'. The earlier meaning of *isopalês* is 'well matched [military groups]', as attested, for example, in the *Histories* of Herodotus:

> After agreeing to these terms, they departed, and the picked men remaining from each side joined battle. As the fighting went on, the two sides were so equally matched [*isopaleôn*] that, finally, as night fell, only three of the original 600 men were left... (Herodotus, *Histories*, 1.82.4; Strassler, 2007, p. 47).

The term conveys the condition in which neither side is able to dominate the other, and it is used by Herodotus in the same sense as *isorropia* (see note 6).

For another example of an early usage of *isopalês*, we turn to Thucydides (*ca*. 460–395 BC):

> On the Athenian side the whole body of hoplites, who were equal in number [*plêthei isopaleis*] to those of the enemy, were marshalled eight deep, and the cavalry on either wing (Thucydides, *The Peloponnesian War*, 4.94.1; Smith, [1920] 1953, pp. 372–373).

The fact that Plato uses different terminology for the same purpose shows that neither word was a technical term for him: the two words (*isorropia* and *isopalês*) express the same concept (as was also the case for Herodotus), which is essentially descriptive.

The translations of *isorropia*, 'equal balance' and 'equilibrium', are probably dependent on the technical usage of this term by Archimedes (*d*. 212 BC), particularly in his *On the equilibrium of planes*. But he lived after both Plato and Aristotle, and it is not appropriate to ascribe his concept of equilibrium to earlier thinkers without unambiguous evidence (Mugler, 1971, p. 80; Dijksterhuis, [1956] 1987, pp. 286–287). Rather, it seems that Archimedes took a descriptive term in ordinary language and gave it a technical meaning. We therefore caution that 'equal balance' or 'equilibrium' may be misleading because of later usages of this concept in technical contexts, starting in the work of Archimedes. The problem with 'equilibrium' is that it suggests the involvement of weight or force, but we find no evidence for either concept in the passages in Plato and Aristotle.

Given the military context in Herodotus and Thucydides for *isorropia* and *isopalês*, and the metaphorical usage of *isorropia* in the Hippocratic corpus, we express dissatisfaction with the rendering, 'equally balanced', for the sense is closer to 'equally matched'. In Plato's argument for stability, we consider 'equal balance' an expression relating to equal tendencies to motion in opposite directions, not to forces or weights on a lever. In light of the idea of dominance in a military context, the concept of equal balance in Plato would mean that there is no direction where the tendency to motion is 'dominant'; if there were such a direction, then the body would move in that direction. Thus, 'equal balance' conveys the cancellation of inclination and, as the concept is neutral with respect to phenomena, specification has to follow: what is it which is in balance.

The passage in the *Timaeus* offers a similar set of problems. Here is Jowett's translation:

> Indeed, when it is in every direction similar [*homoiôs*], how can one rightly give to it names which imply opposition? For if there were any solid body in equipoise [*isopales*] at the centre of the universe, there would be nothing to draw it to this extreme rather than to that, for they are all perfectly similar [*homoiotêta*];... (Plato, *Timaeus*, 62d–63a; Jowett, [1871] 1964, p. 750).

Jowett uses 'similar' and 'equipoise' for *homoiotês* and *isopalês*, respectively. Now, 'similar' reflects the literal reading of *homoiotês*, namely, likeness and it works well in this context. But 'equipoise', a noun meaning balance of forces, does not cohere with the context since no forces are involved.

In several translations of Aristotle's report on the views of Anaximander, we notice two different renderings, one for the noun, *homoiotês* ('indifference'), and another for its adverbial form, *homoiôs* ('equably'). In our view, invoking the term, 'indifference', in this context is misleading—the original Greek term means 'likeness', as in the corresponding passage in Plato. 'Likeness' means that the parts of a geometrical or material object cannot be distinguished from each other by any characteristic (or property). The rendering, 'indifference', is based on an interpretation: Guthrie explicitly follows Stocks in translating (or rather interpreting) *homoiotês* as 'indifference', claiming that this meaning 'becomes clear from the context'.[8] Moreover, in contrast to Guthrie, Stocks is consistent, for he renders *homoiôs* 'indifferently', while noting that the word literally means 'likeness'; indeed, this is its basic meaning according to the standard Greek lexicon.[9] He further refers to Burnet who has 'indifference' in this passage but translates the same word in the *Phaedo* as 'equiformity' (Stocks, 1922, 295a n. 2; Burnet, [1911] 1963, pp. 128–129; Robinson, ([1971] 1972, p. 117 n. 1) concurs with Stocks and Burnet).

This close analysis, in which we sought to uncover the structures of these arguments for stability by adhering as much as possible to the literal meanings of the terms in their own historical contexts and by putting forward minimal interpretations, has consequences that affect some arguments formulated by modern historians and philosophers of science. Our analysis shows that neither symmetry nor equilibrium was applied in the arguments for stability by Plato, Anaximander (as reported by Aristotle) and Aristotle. These powerful concepts were not available to our protagonists; nevertheless, the literature abounds with claims that the arguments are based on symmetry or equilibrium.

4. The Limitations of Powerful Concepts—Symmetry and Equilibrium

It is well known that the mind often imposes its own mode of understanding on the phenomena it encounters. Evidence from the past is no exception; indeed, the past appears familiar as the mind typically conceives of it in terms of current conceptual schemes. This is an aspect of the celebrated hermeneutic problem, but we need not be detained here with this vexing philosophical problem for which the literature is vast and controversial. Rather, we focus on the historical evidence and seek to put things in order, that is, first and foremost, in chronological order, so that diachronic distinctions among several conceptual schemes can be established. In addition to historical ordering, we search for consistency within these schemes. This requires an effort on the part of a reader of ancient texts. We are of the opinion that the effort is worth making as it helps demonstrate how concepts have been made and how they have subsequently evolved. In our book, *From* Summetria *to Symmetry: The Making of a Revolutionary Scientific Concept* (Hon and Goldstein, 2008), we present a sustained argument based on this historiographical approach. Our position is clear: the modern concepts of symmetry and equilibrium are too powerful to do justice to the texts we have discussed; the appeal to these concepts in the unpacking of the arguments we have cited says more about the contemporary analyst than about the historical actor.

Consider Bluck's translation of the passage, discussed above, in the *Phaedo* 108e4–109a6:

> 'I am satisfied', he [Socrates] said, 'in the first place, that if [the Earth] is spherical and in the middle of the universe, it has no need of air or any other force [*anankês*][10] of that sort to make it impossible for it to fall; it is sufficient by itself to maintain the symmetry [*homoiotêta*] of the universe and the equipoise [*isorropian*][11] of the earth itself. A thing which is in equipoise and placed in the midst of something symmetrical [*homoiou*] will not be able to incline more or less towards any particular direction; being in equilibrium [*homoiôs*], it will remain motionless' (Bluck, 1955, p. 130).

This translation does not correspond faithfully to the Greek terms and it is not consistent; for example, as we have pointed out above, *homoiotês* means 'likeness', and not 'symmetry' in either the ancient or the modern sense, and the related term, *homoiôs*, does not mean 'equilibrium'. Essentially, this is more of an interpretation than a translation, and a misleading interpretation at that. Nevertheless, this translation serves our purpose well, for it illustrates the way the passage is commonly understood.

For a prominent example, we turn to Sambursky's analysis:

> In the geocentric picture of the world the arguments offered by the Greeks for the state of rest of the earth in the center were usually based on the principle of sufficient reason: considerations of symmetry show that the earth 'lacks sufficient reason' to move from its central position with regard to the surrounding heavens. The first to make a statement to this effect was Anaximander, and in Aristotle's account of this theory the symmetrical position of the earth with respect to the extremes is described by *homoiotes* (equability), leading to a state of indifference (Sambursky, 1958, p. 331; cf. Sambursky, 1959, pp. 108–109).

Sambursky brings three modern concepts to bear on the ancient arguments we have examined: the principle of sufficient reason, symmetry considerations, and the concept of indifference. He first suggests a general outlook: Greek arguments concerned with the geocentric picture of the world typically rely on the principle of sufficient reason, introduced by Leibniz at the turn of the 18th century. He then links this principle with symmetry considerations, a move which Leibniz did not take for the simple reason that the concept of symmetry, as we know it today, was not available to him (see, e.g. Hon and Goldstein, 2006, pp. 426–427; cf. Hon and Goldstein, 2008, § 1.4). Moreover, Sambursky identifies the condition of *homoiotes* (equability) with a state of indifference. Symmetry considerations, however, do not underpin the principle of sufficient reason, which requires an agent, unlike the concept of indifference (see Hon and Goldstein, 2006, pp. 426–428). In sum, this approach of appealing to three powerful modern concepts does not do justice to the ancient mode of argumentation. Sambursky's analysis does not help us understand classical arguments concerning the stability of the Earth; but it does point to a dominant feature in modern interpretative schemes for these arguments. We turn then to another such example.

According to Makin, Plato's argument and that attributed to Anaximander depend on an indifference argument, based on symmetry considerations:

> ... a minimal version of the indifference argument can be stated as follows. Suppose the cosmos is of such a shape that there is at least one line through it about which it exhibits reflective symmetry: what is on one side of that line is the mirror image of what is on the other. Suppose the earth likewise exhibits reflective symmetry around at least one line. Then that is enough for an indifference argument on all fours [i.e. in full agreement] with Anaximander's to proceed.... In the argument as given by Plato, and as attributed to Anaximander by Aristotle, both the earth and the cosmos exhibit reflective symmetry around far more planes than one (Makin, 1993, pp. 103–104).

Makin begins his study with what he considers a fact, namely, that 'there are arguments concerning *indifference* and ways of thinking involving *symmetry* which resonate strongly with us. Such arguments and ways of thinking', he continues, 'are found in ancient philosophical sources.... They occur also throughout subsequent philosophy and in everyday thought.... We should wonder whether our being struck by considerations of symmetry and balance is indicative of some deep metaphysical commitments' (Makin, 1993, p. 1, italics in the original). Given this approach, it is not surprising that Makin further comments that the kind of argument, which Plato put forward in the *Phaedo* (as well as that attributed to Anaximander), is 'interesting precisely because it admits of the more general formulation' (Makin, 1993, p. 104).

Makin ignores all historical constraints; he projects modern modes of thinking onto the past, as if they can all be unified in one 'general formulation'. In Makin's view the argument is based on symmetry reflection with respect to either a line or a plane, despite the absence of any appeal to mirror reflection in the ancient text. But the ancient arguments are not based on symmetry considerations of any kind. Makin is completely ahistorical in recasting the argument into this 'general formulation' of indifference arguments. He does not produce any evidence to give us confidence that this is the way Plato (or Anaximander, according to Aristotle's report) conceived of it.

One may imagine that these analyses have been superceded by recent discussions of the passages in question. But this is not the case. At the outset of our paper we cited Sedley's translation. This is how he understands the argument in the *Phaedo*:

> It is here that we can bring in Socrates' gloss on 'sufficient': symmetry, he has said, is sufficient to account for the earth's stability in so far as there is then no need for 'air or any other such necessitations' (108e5-109a2). He means that the earth's symmetrical shape and position relative to the heaven is (instrumentally) better than any alternative because it not only maintains an inherently good arrangement, but does so in a way which altogether dispenses with material or mechanical composition.... Symmetry can *more* satisfactorily ensure the earth's stability for not having to rely on any intrinsically unreliable material conditions whatsoever.... on the symmetry principle, *any* stuff placed at the center of a spherical cosmos would have to stay there.... What Socrates says is that the earth's stability does not require 'air or any other *such* necessitation'. And he goes on in effect to substitute a mathematical for a material necessitation with his appeal to the symmetry theory (Sedley, 1989, pp. 365–367, italics in the original).

Sedley produced a careful translation of Plato's *Phaedo* but, when he comes to explaining the arguments, he appeals to the concept of symmetry, assuming without discussion that it is found in the passage. This approach has persisted. For example, Zabell remarks that 'the ancients used symmetry arguments to destroy belief, where we use them to quantify it' (Zabell, 2005, p. 17). Zabell's comment is intended to be perceptive, but in fact it is false—the ancients did not have the concept of symmetry that we apply today.

To be sure, Plato did use the term, *summetria*, elsewhere, but it did not mean in antiquity what it means to a reader today. Plato invoked *summetria* in two senses, commensuration and well proportioned (e.g. Plato, *Theaetetus*, 147d and 148a–b; and Plato, *Timaeus,* 87c–d, respectively). In Greek antiquity symmetry was a single concept with a range of applications, expressing proportionality with a specific constraint. It referred either to a relation between two magnitudes or to a property of an object. Thus, there are two different contexts: in mathematics it had the specific technical meaning of commensurable, while generally it meant suitable, moderate, or well proportioned. The mathematical usage concerns a relation between two magnitudes of the same kind: do they have a common measure? In Euclid, the magnitudes are lengths, areas, and volumes; and in Archimedes, they also include weights and times. The other usage involves a judgment arrived at by comparison with an ideal in the relevant domain in order to establish a certain property of an object, namely, that it is beautiful or that it functions properly. The former application is scientific and the latter aesthetic (see Hon and Goldstein, 2008, chapters 2 and 3). Clearly, these meanings connote neither likeness nor equal balance. Thus, for Plato the argument in the *Phaedo* is definitely not an argument based on symmetry considerations.

As we have seen, unlike Bluck, Sedley is careful not to introduce 'symmetry' into the translation. However, he is more than willing to cast the argument in symmetrical terms in several ways: (1) symmetry as a property of shape, (2) symmetry in the form of a principle, and finally (3) symmetry as a theory. Needless to say, Sedley does not elaborate on his own usages of 'symmetry', and he takes it for granted that all of them are familiar to the reader. Makin is more systematic in his approach. While he appeals to 'reflective symmetry', he also puts the following definition in his Introduction:

> An indifference argument typically contains a premiss concerning symmetry... (Makin, 1993, p. 6).

This is a very helpful remark; it characterizes indifference arguments. But in the arguments we have discussed there is no claim concerning symmetry. As we have shown above, in their ancient settings these arguments do not include claims based on symmetry considerations, and thus—by Makin's own definition—these are not indifference arguments. To be sure, Makin can recast the arguments to suit his design, but then the discussion is no longer about Plato and Aristotle.

Like Sedley, we distinguish between inserting 'symmetry' in the translation, on the one hand, and appealing to the concept in the interpretation of the argument, on the other. But, unlike Sedley and others who hold that this mode of argumentation about stability relies on symmetry considerations, we submit that nothing of the kind is involved. Moreover, we distinguish between 'symmetry considerations' and 'symmetry argument': the former is intentionally vague, while the latter is technically precise.

The expression 'symmetry argument' is a relatively recent coinage. Like any argument, a symmetry argument has several components comprising a definite structure, namely, premises and rules of inference which lead to a conclusion. By symmetry argument we mean that symmetry may enter any or all of the three components that comprise an argument. Typically, a symmetry argument has premises that refer to symmetrical properties whose consequences with respect to some structure can be seen in the conclusion of the argument mediated by a rule of inference (for a discussion of symmetry arguments, see Hon and Goldstein, 2006; cf. van Fraassen, 1989, p. 233). We have examined the ancient texts and we do not see any evidence of symmetry arguments; the arguments make perfect sense without an anachronistic appeal to modern concepts.

So much then for symmetry. We now disengage 'equal balance' in Plato from 'equilibrium' in Archimedes. As we have indicated, the process of balancing requires specification, namely, what is the thing that is shown to be in balance? In other words, the balance is neutral with respect to phenomena and specification is required to put it to use. This is not the case with equilibrium, where the concept implies the balancing of weights. The *locus classicus* of equilibrium and its first technical definition comes, of course, in a work by Archimedes, in the century after Plato.

At the outset of *Equilibrium of Planes,* Archimedes states:

> Postulate 1. We postulate that equal weights at equal distances are in equilibrium [*isorropein*], and that equal weights at unequal distances are not in equilibrium, but incline towards the weight which is at the greater distance (Mugler, 1971, p. 80; Dijksterhuis, [1956] 1987, pp. 286–287).

Here we have unambiguous evidence that for Archimedes the Greek term, *isorropein*, connotes weights which are equally balanced, in equilibrium. But that does not settle the question of the meaning of the term *isorropein* prior to Archimedes. The postulate exhibits a precise formulation of a concept which, in Plato's usage, is only descriptive and certainly not technical.

For the purpose of distinguishing 'symmetry' from 'equilibrium' it suffices to cite two consecutive propositions in this treatise by Archimedes:

> [6] Commensurable [*summetra*] magnitudes are in equilibrium [*isorropeonti*] at distances reciprocally proportional to the weights (Mugler, 1971, p. 85; Dijksterhuis, [1956] 1987, p. 289).
> [7] However, even if the magnitudes are incommensurable [*asummetra*], they will be in equilibrium [*isorropêsounti*] at distances reciprocally proportional to the magnitudes (Mugler, 1971, p. 87; Dijksterhuis, [1956] 1987, p. 305).

Archimedes' appeal to *summetra* and *asummetra* in this context is clearly Euclidean and has nothing to do with symmetry arguments of the kind developed—as we have seen—by modern commentators. Archimedes demonstrates that equilibrium holds under certain specified conditions. In contrast to Plato, he made the definition mathematically precise. We have argued that 'equilibrium' as the translation of *isorropia* or *isopalês* is misleading, and that Plato did not have the later (technical) concept of equilibrium (as defined by Archimedes) in mind. So the claim that 'symmetry' is part of Plato's argument, based on his appeal to equilibrium, fails (see, e.g. Bluck, 1955, p. 130, cited above).

At a later point in time equilibrium began to mean the balancing of forces, that is, a condition in which (in modern terms) the vectorial sum of all the forces acting on the body vanishes. This is probably the relevant meaning of equilibrium in modern interpretations of the ancient texts, rather than that of weights attached to a lever as it had been postulated by Archimedes. For example, according to Sambursky, the first time a description of equilibrium resulting from the symmetrical action of forces occurs is in a text from late antiquity that reports the physical views of the Stoics. Sambursky cites Achilles (probably third century, AD; for this dating of Achilles, see Neugebauer, 1975, p. 950) to this effect:

> The Stoics use the following example to prove the state of rest of the earth.... If one takes a body and ties it from all sides with cords and pulls them with precisely equal force [*isorropôs*], the body will stay and remain in its place, because it is dragged equally from all sides.[12]

Sambursky refers to this case as 'a perfect example of a dynamic equilibrium', and it is certainly different from the sense of equilibrium in Archimedes. Hence we recognize that a certain development in the concept took place, but this should in no way affect our understanding of the arguments of Plato and Aristotle—chronologically and thus conceptually these two great thinkers belong to an earlier era. Although this passage in Achilles alludes to the problem discussed by Plato and certainly has the same consequence, it depends on a different conceptual framework.

5. *Did Plato and Aristotle Apply Symmetry Arguments?*

In the Introduction to *Symmetries in Physics: Philosophical Reflections*, the editors, Katherine Brading and Elena Castellani, discuss symmetry arguments and characterize the general form which such arguments most frequently take:

> a situation with a certain symmetry evolves in such a way that, in the absence of an asymmetric cause, the initial symmetry is preserved. In other words, breaking of the initial symmetry cannot happen without a reason, or *an asymmetry cannot originate spontaneously* (Brading and Castellani, 2003, pp. 9–10, italics in the original).

Thus, when the symmetrical properties of the premises are conserved in the conclusion (arrived at by some rule of inference) it means that no reason (or cause) has been adduced to break the presupposed symmetrical properties of the system under consideration.

It is commonly claimed that a certain argumentative structure in antiquity can be recast in the form of a symmetrical argument. The claim is that this scheme works for the analysis of ancient philosophical arguments. This received view, with which Brading and Castellani concur, underlies interpretations of certain Greek texts and affects their translations. Given the historical fact that symmetry arguments are based on the modern concept of symmetry, which is essentially a 19th-century development, we do not accept the received view that there are symmetry arguments in antiquity (see Hon and Goldstein, 2006, pp. 426–429). To be sure, the modern analyst is free to cast such arguments into a modern matrix, but this practice does not facilitate the understanding of these arguments in their ancient settings.

In a recent paper Belot recasts a passage in the *Timaeus* (62c–63a) that we have cited above, claiming that the argument there may be presented in group-theoretic terms, thus illustrating a symmetry argument. He begins by 'idealizing' Plato's cosmos, and that includes giving specific modern meanings to the various terms as well as introducing the modern concept of symmetry. In effect, Belot tailors the general frame of Plato's argument to fit group-theoretic requirements; he thus looks for the ingredients that are necessary for the symmetry argument to work. In this case, the ancient text is used as an opportunity to demonstrate the power of group theory and symmetry transformations. Belot has analyzed one of the key assumptions in this passage of the *Timaeus*—likeness—but he did not address the other assumption, equal balance. The modern concept of symmetry is powerful enough to carry out the argument with just one premise. However, as we have seen, the original text indicates that Plato's argument is based on both assumptions—likeness and equal balance. We see no problem in 'clothing' the ancient argument in modern dress as long as it is clear that the analyst redesigns, as it were, the original 'cloth'. In short, Belot's analysis does not throw any light on Plato's argument (see Belot, 2005, pp. 257–259).

We have presented the relevant texts with the goal of analyzing them faithfully in terms of concepts invoked in antiquity. We have also demonstrated the extent to which those who rely on the received view have been misled by powerful modern concepts such as symmetry.

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NOTES

1. Aristotle, *De caelo*, ii.13, 293b32; Stocks, 1922: 'Others, again, say that the earth, which lies at the centre, is 'rolled', and thus in motion, about the axis of the whole heaven. So it stands written in the *Timaeus*'.
2. Presumably Anaximander did not use these terms either, but this is speculative. For a discussion of Aristotle's ascription of this argument to Anaximander, see Robinson [1971] 1972, pp. 111–118. For a response to Robinson's position, see O'Brien, 1984, pp. 325–326.
3. We therefore take issue with Robinson ([1971] 1972, pp. 112–113) who considers the second premise redundant.
4. Stocks, 1922, 295a n. 2; note that in antiquity Simplicius had already associated these arguments of Plato and Anaximander: see Mueller, 2005, p. 75. Cf. Furley, 1989, p. 18. For another account of the similarity between Aristotle's description of Anaximander's claim and that of Plato in the *Phaedo*, see Leggatt, 1995, p. 262.
5. This view is expressed by Simplicius in commenting on a passage in Aristotle's *De caelo* ii.14; see Mueller, 2005, p. 83: 'Perhaps [Aristotle] means by "the extremity of the place which surrounds the centre" the highest part of the air, to which fire moves,...'. Cf. Furley, 1989.
6. In the Greek-English Index appended to his translation, Mueller (2005, p. 161) defines *isorropia* as 'even balance' (a noun), and *isorropos* as 'evenly balanced' (an adjective).
7. Herodotus, *Histories*, 5.91.1; Strassler, 2007, p. 405. For a usage in Aristotle of an inflected form related to *isorropia*, see his *De partibus animalium*, iv.12 (695a10–12); Lennox, 2001, p. 112 (concerning birds): '... and has placed the legs beneath the mid-section, so that, with an equal distribution [*isorropou*] of weight [*barous*] on either side, they [birds] are able to walk about and to stand'. Interestingly, the concept of *isorropia* (equal balance) does not mean that *weights* are in balance—this has to be specified.
8. Guthrie, 1939, 234 n. *a*. According to Stocks (1922), Aristotle (295b11) reports the view of Anaximander as follows: 'the earth keeps its place because of its indifference [*homoiotêta*]'.
9. Stocks, 1922, 295b13: '... that which is set at the centre and indifferently related to every extreme point;...'. Liddell, Scott and Jones [1968] 1996, p. 1224.
10. Sedley (1989) correctly translates this term 'necessitation'. For the corresponding passage in the 12th century translation of the *Phaedo*, see Minio-Paluello, 1950, p. 75 (*Phaedo* 109a: '... neque aere ad non cadendum, neque alia necessitate aliqua tali,...'.). See also *Timaeus* 47e-48a, where Cornford ([1937] 1966, p. 160) has 'Necessity', as does Bury ([1929] 1975, p. 109).

11. In the 12th-century translation of the *Phaedo* (see Minio-Paluello, 1950), the Greek word, *isorropian*, is simply transliterated as 'isorropiam', perhaps an indication that an equivalent Latin term was not commonly available at this time. For example, William of Moerbeke (13th century) used 'equerepo' and 'equaliter repo' in Latin to translate *isorropeô* in the works of Archimedes: Clagett, 1976, p. 670. For a comparable case, where Greek *summetria* was transliterated as 'symmetria' for lack of an equivalent Latin term, see Pliny, *Historia naturalis*, XXXIV.65.
12. Sambursky, 1958, pp. 331–332; Achilles, *Isagoga excerpta*, § 4; Maass, [1898] 1958, p. 34. As far as we can determine, this sense of equilibrium which, in modern terms, means that the vector sum of forces acting at a point is zero, is most unusual in the literature of physics prior to the 17th century.

REFERENCES

Achilles. *Isagoga excerpta*. See Maass, [1898] 1958.

Archimedes. *On the equilibrium of planes*. See Dijksterhuis, [1956] 1987, and Mugler, 1971.

Aristotle. *De caelo*. See Guthrie, 1939; Leggatt, 1995; Mueller, 2005; and Stocks, 1922.

Aristotle. *De partibus animalium*. See Lennox, 2001.

Belot, G. (2005) 'Dust, time and symmetry', *British Journal for Philosophy of Science*, 56, 255–291.

Bluck, R. S. (tr.) (1955) *Plato's Phaedo*. A translation of Plato's *Phaedo* with introduction, notes and appendices (London: Routledge & Kegan Paul).

Brading, K. and Castellani, E. (eds.) (2003) *Symmetries in physics: philosophical reflections* (Cambridge: Cambridge University Press).

Burnet, J. (ed.) [1911] (1963) *Plato's Phaedo, edited with introduction and notes* (Oxford: Clarendon Press).

Bury, R. G. (ed.) (tr.) [1929] (1975) *Plato in twelve volumes*, Vol. 9. *Plato: Timaeus*. Loeb classical library (Cambridge, MA: Harvard University Press; London: Heinemann).

Cicero. *De natura deorum*. See Rackham, 1928.

Clagett, M. (1976) *Archimedes in the middle ages*, Vol. 2. *The translations from the Greek by William of Moerbeke*. Memoirs of the American Philosophical Society, 117 (Philadelphia: American Philosophical Society).

Cornford, F. M. (tr.) [1937] (1966) *Plato's Cosmology. The Timaeus of Plato*. Translated with a running commentary (London: Routledge).

Cornford, F. M. (tr.) (1959) *Plato's Theaetetus* (Indianapolis and New York: Bobbs Merrill).

Dijksterhuis, E. J. [1956] (1987) *Archimedes* [Trans. Dikshoorn, C] (Princeton: Princeton University Press).

Eliot, C. W. (ed.) (1909) *The Apology, Phaedo and Crito of Plato*. Translated by Jowett, B (New York: Collier and Son).

Fowler, H. N. (ed.) (tr.) [1914] (1933) *Plato in twelve volumes*, Vol. 1. *Plato: Phaedo*; Introduction by W. R. M. Lamb. The Loeb classical library (Cambridge, MA: Harvard University Press; London: William Heinemann).

van Fraassen, B. C. (1989) *Laws and symmetry* (Oxford: Clarendon Press).

Furley, D. (1989) 'The dynamics of the earth: Anaximander, Plato, and the centrifocal theory', in: *Idem*, *Cosmic problems essays on Greek and Roman philosophy of nature* (Cambridge: Cambridge University Press), pp. 14–26.

Guthrie, W. K. C. (ed.) (tr.) (1939) *Aristotle: On the heavens*. The Loeb classical library (Cambridge, MA: Harvard University Press; London: William Heinemann).

Herodotus. *Histories*. See Strassler, 2007.

Hon, G. and Goldstein, B. R. (2006) 'Unpacking "for reasons of symmetry": two categories of symmetry arguments', *Philosophy of Science*, 73, 419–439.

Hon, G. and Goldstein, B. R. (2008) *From Summetria to symmetry: the making of a revolutionary scientific concept*. Archimedes: New Studies in the History and Philosophy of Science and Technology, 20 (Dordrecht: Springer).

Jowett, B. (tr.) [1871] (1964) *The dialogues of Plato, translated into English*, 4th edn, 4 vols. (Oxford: Clarendon Press, vol. 3).

Kirk, G. S. and Raven, J. E. [1957] (1966) *The Presocratic philosophers*: *a critical history with a selection of texts* (Cambridge: Cambridge University Press).

Leggatt, S. (ed.) (tr.) (1995) *Aristotle: On the heavens, I and II* (Warminster: Aris & Phillips).

Lennox, J. G. (tr.) (2001) *Aristotle: On the parts of animals* (Oxford: Clarendon Press).

Liddell, H. G., Scott, R. and Jones, H. S. [1968] (1996) *A Greek-English lexicon*. Revised and augmented with the assistance of R. McKenzie (Oxford: Clarendon Press).

Maass, E. (ed.) [1898] (1958) *Commentariorvm in Aratum reliqviae* (Berlin: Weidmann).

Makin, S. (1993) *Indifference arguments* (Oxford: Blackwell).
Mill, J. S. [1843] (1941) *A system of logic* (London, New York and Toronto: Longmans, Green and Co.).
Minio-Paluello, L. (ed.) (1950) *Phaedo: Interprete Henrico Aristippo*. Plato Latinus, R. Klibansky (ed.), Vol. 2 (London: Warburg Institute).
Mueller, I. (tr.) (2005) *Simplicius On Aristotle's On the heavens 2.10-14* (Ithaca: Cornell University Press).
Mugler, C. (ed.) (tr.) (1971) *Archimède: Des spirales, De l'équilibre des figures planes, L'arénaire, et La quadrature de la parabole* (Paris: Les Belles Lettres).
Neugebauer, O. (1975) *A history of ancient mathematical astronomy* (Berlin and New York: Springer).
O'Brien, D. (1984) *Plato weight and sensation: the two theories of the 'Timaeus'* (Leiden: Brill).
Plato. *Phaedo*. See Bluck, 1955; Burnet, [1911] 1963; Eliot, 1909; Fowler, [1914] 1933; Jowett, [1871] 1964; Minio-Paluello, 1950; and Sedley, 1989.
Plato. *Theaetetus*. See Cornford, 1959.
Plato. *Timaeus*. See Bury, [1929] 1975; Cornford, [1937] 1966; and Jowett, [1871] 1964.
Pliny. *Historia naturalis*. See Rackham, 1952.
Rackham, H. (ed.) (tr.) (1928) *Cicero: De natura deorum*. Loeb classical library (Cambridge, MA: Harvard University Press; London: William Heinemann).
Rackham, H. (ed.) (tr.) (1952) *Pliny: Natural history*. Books 33–35. Vol. 9. Loeb classical library (Cambridge, MA: Harvard University Press; London: William Heinemann).
Robinson, J. [1971] (1972) 'Anaximander and the problem of the earth's immobility', in: J. P. Anton and G. L. Kustas (eds.) *Essays in ancient Greek philosophy* (Albany: State University of New York Press), pp. 111–118.
Sambursky, S. (1958) 'On some references to experience in Stoic physics', *Isis*, 49, 331–335.
Sambursky, S. (1959) *Physics of the Stoics* (London: Routledge and Kegan Paul).
Sedley, D. (1989) 'Teleology and myth in the Phaedo', *Proceedings of the Boston Area Colloquium in Ancient Philosophy*, 5, 359–383.
Smith, C. F. (tr.) [1920] (1953) *Thucydides: History of the Peloponnesian war*, 4 vols. (London: Heinemann and Cambridge, MA: Harvard University Press, vol. 2).
Stocks, J. L. (tr.) (1922) *Aristotle: De caelo* (Oxford: Clarendon).
Strassler, R. B. (ed.) (2007) *The landmark Herodotus. The histories* [Trans. Purvis, A. L. with an Introduction by R. Thomas] (New York: Pantheon).
Thucydides. *The Peloponnesian war*. See Smith, [1920] 1953.
Vlastos, G. (1995) *Studies in Greek philosophy, vol. 1: the Presocratics* (Princeton: Princeton University Press).
Zabell, S. L. (2005) *Symmetry and its discontents: essays on the history of inductive probability* (Cambridge: Cambridge University Press).