PROJECTILE MOTION IN ARISTOTLE'S *PHYS.* Θ. 10

In *Phys.* Θ. 10 Aristotle sets out to show that the prime mover lacks parts or magnitude, which means that the prime mover is immaterial. In order to do this he first proves three lemmas: (a) no finite material body can cause eternal motion (*Phys.* 266a10-23), (b) no finite material body can have an infinite δύναμις (*Phys.* 266a23-b6) and (c) no infinite material body can have a finite δύναμις (*Phys.* 266b6-24)[1]. At the end of *Phys.* Θ. 10 (267b17-26) Aristotle concludes from (a) and (b) that the prime mover cannot be a finite material body; the complementary conclusion that the prime mover cannot be an infinite material body follows not from (c), as one would expect, but from the fact that the existence of infinite material bodies has already been ruled out ἐν τοῖς φυσικοῖς[2]. In this paper I will attempt to answer two questions arising from the fact that, after establishing (a)-(c) and before drawing one prong of his conclusion from (a) and (b), Aristotle embarks on an explanation of projectile motion and a critique of a rival theory which explains projectile motion by means of the ἀντιπερίστασις (*Phys.* 266b28-267a20): is Aristotle's explanation consistent with his theory of motion and how does this explanation, as well as the critique of the rival theory, bear on its context?[3]

Aristotle credits the ἀντιπερίστασις theory to some anonymous thinkers

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1. Aristotle opens *Phys.* Θ. 10 by laying down the conclusion he aims at, i.e. that the prime mover lacks magnitude, and notes that he will establish first some preliminary results, one of which is (a): "Οτι δὲ τοῦτ' ἀμερὲς ἀναγκαῖον εἶναι καὶ μηδὲν ἔχειν μέγεθος, νῦν λέγωμεν, πρῶτον περὶ τῶν προτέρων αὐτοῦ διορίσαντες. τούτων δ' ἓν μέν ἐστιν ὅτι οὐχ οἷόν τε οὐδὲν πεπερασμένον κινεῖν ἄπειρον χρόνον (266a10-13). (b) and (c) are by implication two further preliminary results; cf. W. D. Ross, *Aristotle's Physics*, Oxford 1936, p. 721.

2. That it, in *Phys.* Γ. 4-7 and *Cael.* 1.5-7; cf. D. Graham, *Aristotle's Physics, Book VIII*, Oxford 1999, p. 171.

3. *Phys.* Θ. 10 raises a host of other problems. It is clear why a finite material body cannot be the prime mover in view of (a) – Aristotle has posited the prime mover in order to explain the eternity of motion on the cosmic scale (*Phys.* 267b24-25) and, if a finite material body cannot cause eternal motion, the prime mover cannot be any finite material body: (a), however, is riddled with difficulties (see Graham [above, n. 2], pp. 167-170) and it is by no means clear what material bodies Aristotle has in mind in this proof. Equally unclear is why a finite material body could be a fitting candidate for the prime mover if, as follows from (b), this body had an infinite δύναμις or why Aristotle bothers to prove (c) since at the end of *Phys.* Θ. 10 he does not utilize this result.

who can only be Plato and perhaps other members of the Academy who had adopted the *Timaeus* physics[4]. Plato notes in passing at *Tim.* 79e10-80a6 that projectile motion as well as other phenomena are to be explained in the same manner as the successive processes of exhalation and inhalation, which for Plato are typical cases of what Aristotle calls ἀντιπερίστασις. In exhalation a quantity of air is expelled from the lungs but, since there is no vacuum to receive it, the expelled air displaces a contiguous quantity of air which also displaces another quantity contiguous with it and so on until a last displaced quantity of air is driven into the lungs, i.e. the place vacated by the exhaled quantity of air (*Tim.* 79b1-c1); this air is driven into the lungs through the pores in the skin and is also expelled through the pores setting off a second ἀντιπερίστασις that forces a quantity of air into the respiratory passages (*Tim.* 79c1-d1)[5]. ἀντιπερίστασις is thus a type of motion necessitated by the absence of vacuum and is likened by Plato to a turning wheel (*Tim.* 79b7-c1). For a proponent of ἀντιπερίστασις, as Barnes puts it, «motion does not require *any* vacancies. Let *b* occupy *p* up to *t*: then *a* may move to *p* at *t* provided that there are two series of bodies, $c_1 \ldots c_n$ and $d_1 \ldots d_m$ such that, first, the places occupied by *a*, *b*, each c_i and each d_i are all identical in shape and size, and, second, *a* is contiguous with c_1, c_1 with c_2, ... c_{n-1} with c_n, c_n with *b*, *b* with d_1, d_1 with d_2, d_{m-1} with d_m, and d_m with *a*. Then *a* may move to *p* at *t*, provided that each of the contiguous bodies moves, at the same time and at the same speed, to fill its neighbour's position. Imagine a card circle, divided by two diameters into quarters labeled *a*, *c*, *b*, *d*. At *t* revolve the circle through 180°; then *a* comes to occupy the place of *b*; and at no time is any part of the circle empty»[6]. Although Plato does not explain how the ἀντιπερίστασις is supposed to account for projectile motion, he seems to assume that the thrown projectile displaces contiguous quantities of air and is thus moved by the quantity of air which instantaneously flows round to the place

4. Cf. Simplicius, *In Phys.* 1351.28-29 (Diels): Ἐπειδὴ δὲ ὁ Ἀλέξανδρος τοῦ Πλάτωνος δόξαν εἶναί φησιν τὸ κατὰ ἀντιπερίστασιν γίνεσθαι τὴν τῶν ῥιπτουμένων κίνησιν [...].

5. A concise description of Plato's account of respiration is given by Aristotle, *Resp.* 472b13-20: ἐξιόντος γὰρ ἔξω τοῦ θερμοῦ διὰ τοῦ στόματος, τὸν περιέχοντα ὠθούμενον ἀέρα φερόμενον ἐμπίπτειν εἰς τὸν αὐτὸν τόπον φησὶ διὰ μανῶν οὐσῶν τῶν σαρκῶν, ὅθεν τὸ ἐντὸς ἐξῄει θερμόν, διὰ τὸ μηδὲν εἶναι κενὸν ἀντιπεριισταμένων ἀλλήλοις· θερμανθέντα δὲ πάλιν ἐξιέναι κατὰ τὸν αὐτὸν τόπον, καὶ περιωθεῖν εἴσω διὰ τοῦ στόματος τὸν ἀέρα τὸν ἐκπίπτοντα θερμόν· καὶ τοῦτο δὴ διατελεῖν ἀεὶ ποιοῦντας, ἀναπνέοντάς τε καὶ ἐκπνέοντας. Cf. Galen, *Plac. Hipp. et Plat.* 8.8-9.

6. J. Barnes, *The Presocratic Philosophers*, vol. 2, London 1979, pp. 98-99. Cf. Simplicius, *In Phys.* 1350.31-36 (Diels): ἀντιπερίστασις δέ ἐστιν, ὅταν ἐξωθουμένου τινὸς σώματος ὑπὸ σώματος ἀνταλλαγὴ γένηται τῶν τόπων, καὶ τὸ μὲν ἐξωθῆσαν ἐν τῷ τοῦ ἐξωθηθέντος στῇ τόπῳ, τὸ δὲ ἐξωθηθὲν τὸ προσεχὲς ἐξωθῇ καὶ ἐκεῖνο τὸ ἐχόμενον, ὅταν πλείονα ᾖ, ἕως ἂν τὸ ἔσχατον ἐν τῷ τόπῳ γένηται τοῦ πρώτου ἐξωθήσαντος.

vacated when the projectile is moved by the thrower so as to prevent the formation of a vacuum[7].

Aristotle does not reject ἀντιπερίστασις: he admits that this type of locomotion takes place in water or air but contends that it is not sufficient to explain projectile motion because the ἀντιπερίστασις in air stops as soon as a quantity of air finds itself in the place originally occupied by the projectile before it was moved by the thrower (*Phys.* 267a15-20)[8]. On Aristotle's account of projectile motion the thrower of the projectile does not simply move contiguous quantities of air, as must be the case on Plato's account, but somehow enables a quantity of air to move the projectile, for air and water are capable of both moving something and being moved by something (*Phys.* 267a2-5). Air does stop being moved as soon as the thrower of the projectile stops moving it (equivalently as soon as a displaced quantity of it occupies the place vacated by the projectile) but at the same time it somehow moves a contiguous quantity of air which moves the projectile further and so on (*Phys.* 267a5-8). The projectile is thus moved by a chain of derivative contiguous movers after it is detached from the thrower (*Phys.* 267a14-15: οὐ γὰρ ἓν τὸ κινοῦν, ἀλλ' ἐχόμενα ἀλλήλων; cf. *Phys.* 267b12-15). Graham, the most recent commentator of *Phys.* Θ, objects that Aristotle's explanation «remains rather *ad hoc*: nothing else will explain the phenomenon of projectile motion, so this must be the correct explanation. But an objector might fairly ask why it is that a derivative mover is a mover? What other event accounts for its being a mover, given that when the original mover (or some original mover) is not in contact with it, it does not move anything? [...] The only properties which air seems to have are hotness and wetness (*GC* II. 5, 330b4), neither of which is a proper candidate for sustaining an active power of motion»[9]. Graham concludes that in *Phys.* 266b28-267a20 «Aristotle seems to be flirting with an impetus theory»[10] and that, as a consequence, his

7. Cf. Plutarch, *Plat. Quaest.* 1005a10-13: τὰ δὲ ῥιπτούμενα βάρη τὸν ἀέρα σχίζει μετὰ πληγῆς ἐμπεσόντα καὶ διίστησιν· ὁ δὲ περιῤῥέων ὀπίσω, τῷ φύσιν ἔχειν ἀεὶ τὴν ἐρημουμένην χώραν διώκειν καὶ ἀναπληροῦν συνέπεται τῷ ἀφιεμένῳ τὴν κίνησιν συνεπιταχύνων. There is, however, no evidence in *Tim.* 79e10-80a6 that for Plato the action of air increases the initial speed of the projectile.

8. As Simplicius puts it, ἀντιπερίστασις cannot explain projectile motion because projectile motion causes ἀντιπερίστασις, is not caused by it (*In Phys.* 1351.12-16 [Diels]: καὶ γὰρ ἀντιπεριστάσεως μὲν γινομένης ἡ κίνησις ἐπιτελεῖται, οὐ μὴν διὰ τὴν ἀντιπερίστασιν. ὡς γὰρ ἐπὶ τοῦ βαδίζοντος ἀντιπερίστασις μὲν γίνεται, οὐ μὴν τοῦ βαδίζειν ἡ ἀντιπερίστασις αἰτία, οὕτω καὶ ἐπὶ τῶν ῥιπτουμένων ἄλλο τι τῆς κινήσεως αἴτιόν ἐστιν, καὶ οὐχὶ ἡ ἀντιπερίστασις).

9. Graham (above, n. 2), p. 174.

10. This view is elaborated by E. Hussey, *Aristotle's Physics: Books III and IV*, Oxford 1991, pp. 230-236.

views on projectile motion «undermine his own mechanics, and ultimately require a rethinking of his first principles»[11].

A second problem with the account of projectile motion in *Phys.* Θ. 10 seems to have gone unnoticed. Aristotle does not give any clue as to how this account ties in with its context but the question is inevitably raised: why does he embed a critique of Plato's explanation of projectile motion and his own explanation of this type of forced motion in an elaborate argument to the effect that the prime mover is not a material body? There is a tendency to isolate Aristotle's explanation of projectile motion from its context and treat it as a self-contained essay on the type of motion whose explanation played an important role in the development of classical mechanics. This tendency certainly smacks of the, often unavoidable, teleological approach to the history of science[12] and, though it does bring out the (*sub specie posteritatis*) weak points in Aristotle's account, it loses sight of the central fact that, no matter how strenuously the explanation of projectile motion might have exercised Aristotle, *Phys.* Θ. 10 is the most unlikely context for what is rightly taken to be his final views on the topic. One cannot plausibly assume that in *Phys.* Θ. 10 Aristotle is interested in projectile motion *per se*: he must be concerned with projectile motion in so far as this forced motion bears on the task he sets himself in *Phys.* Θ. 10, namely to show that the prime mover cannot be a finite or an infinite material body.

Aristotle's explanation of projectile motion is in many respects unsatisfactory but not in that he cannot account by his own lights for how air is able to move the projectile as Graham takes it. Hotness and wetness are not the only properties of air. This element also moves naturally downwards or upwards (cf. *Phys.* 216a29-33, *Cael.* 310a16-20) and in *Cael.* 3.2, where Aristotle argues that the elements do have a natural motion, he accounts for the forced motion of the elements by an analogy with projectile motion (301b17-31): as a projectile is moved by a series of consecutive moved movers, that is air masses (cf. *Phys.* 266b28-267a20), a mass of an element is similarly forced to move exclusively by the action of air. Air is by its nature both heavy and light (*Cael.* 301b22-25) so that, when e.g. a stone is thrown (the example Aristotle

11. Graham (above, n. 2), p. 175.

12. For an excessive reaction to this tendency see H. S. Lang, *The Order of Nature in Aristotle's Physics*,Cambridge 1998, p. 213, who objects to the sheer use of the term «projectile motion» in discussions of Aristotle's physics: by her lights this term «is associated with problems concerning the dynamics of moving bodies, and these problems are not found in Aristotle's physics because they represent and require concepts entirely foreign to both his science and his determinate world».

uses in *Cael.* 301b17-31), air can force this piece of earth to move upwards inasmuch as it is light and thus moves naturally upwards. In order to account for how air is assumed to move the projectile in *Phys.* Θ. 10 Alexander of Aphrodisias suggested that air is made self-moving by the thrower of the projectile and supported his suggestion by referring to *Cael.* 3.2 – as soon as air stops being moved by the thrower of the projectile, it becomes self-moving in that it moves naturally thereby forcing the projectile to move[13]. In *Phys.* Θ natural motion is not of course self-motion in the strict sense of the term but any naturally moving body is set in motion by an agent who makes it move naturally (*Phys.* 254b33-256a3) and in the case of projectile motion this agent should be identified with the thrower of the projectile.

The event which, as Graham puts it, accounts for air being a mover of the projectile i.e. for its being made to move naturally so as to move the projectile, is the thrower's moving the projectile in air. In *Phys.* 216a27-29 Aristotle notes that, as a cube submerged in water displaces an equal volume of water, similarly anything moving in air displaces a volume of air equal to its own volume; in general placing anything in a body (i.e. in an element) which cannot be compressed and thus can only be displaced necessarily results in a displacement of this body in the direction in which it is displaced by nature. In view of *Phys.* 216a27-29 a part of this element is displaced downwards or upwards, if the natural motion of this body is downward or upward as is the case with earth and fire respectively; alternatively, a part of this element can be displaced in either direction if the element in question can move by nature in either direction (*Phys.* 216a29-33: water and air are both heavy and light and so they can move naturally either upwards or downwards; cf. *Cael.* 301b23-25). By moving, therefore, a projectile in air so as to throw it the thrower displaces a quantity of air from the place where it naturally rests thereby making it move naturally but, since air cannot be compressed, the displaced quantity of air can only displace another quantity, which is also made to move naturally, and so on – that is, the thrower of the projectile sets off an ἀντιπερίστασις of air masses.

Moving a projectile in air has the same effect on this element as the impact of a chunk of earth would have on the already accumulated earth if, as Aristotle hypothesizes in *Cael.* 297a12-30, the spherical Earth were

13. *Apud* Simplicius, *In Phys.* 1346.29-1347.2, 1347.31-37 and 1348.12-15 (Diels). Assuming that the account of projectile motion in *Cael.* 3.2 is consistent with that *Phys.* Θ. 10, Lang (above, n. 12), pp. 213-214 argues that in light of *Cael.* 3.2 the air moves a projectile as any container moves what is contained in it. Although a projectile is undoubtedly contained in air, nothing in *Cael.* 3.2 or *Phys.* Θ. 10 suggests that Aristotle accords to this fact any explanatory role.

formed by chunks of earth which move naturally towards the center of the universe[14]. Impacting on earth which has already settled around the center (and is not naturally moving any more), a naturally moving mass of earth would displace a chunk of earth from its natural resting place. Since, however, the displaced earth can nothing but move naturally towards the center displacing the earth in front, each impact causes a chain-like displacement of parts of the Earth as the larger ones displace the smaller ones in front and make them move naturally so that they are all «pushed together and make way for one another» until they finally come to rest in equal distances from the center, filling up every available place and thus forming a sphere[15]. Since parts of earth can «make way for one another» only by undergoing ἀντιπερίστασις[16], by moving a projectile in order to throw it the thrower must also displace successive parts of air from their resting places and cause them to be «pushed together and make way for one another» as they all strive to rest equally close to their natural place and fill up every available part of it.

One of these quantities of naturally moving air necessarily winds up in the place vacated by the projectile when it was moved by the thrower, exactly as a liquid rushes instantaneously in the wake of anything moving through it (otherwise there would ensue a temporary vacuum). Although this quantity of naturally moving air stops being moved by the thrower as soon as it settles in the place the projectile left, it is simultaneously contiguous with the projectile and naturally moving, for it cannot gradually fill the place vacated by the projectile when it was moved by the thrower (otherwise there would ensue a temporary vacuum). Thus a quantity of naturally moving air assumes the thrower's role as the mover of the projectile in virtue of its natural motion: it propels the projectile by overwhelming the projectile's downward

14. Lang (above, n. 12), p. 214 also relates Aristotle's thought experiment in *Cael.* 297a12-30 to his account of forced motion in *Cael.* 3.2 but she seems to assume that the thought experiment bears on the motive action of naturally moving air which in *Cael.* 3.2 explains why the natural motion of e.g. a stone is made faster, not why a thrown stone is forced to move unnaturally.

15. *Cael.* 297a8-12: σχῆμα δ' ἔχειν σφαιροειδὲς ἀναγκαῖον αὐτήν· ἕκαστον γὰρ τῶν μορίων βάρος ἔχει μέχρι πρὸς τὸ μέσον, καὶ τὸ ἔλαττον ὑπὸ τοῦ μείζονος ὠθούμενον οὐχ οἷόν τε κυμαίνειν, ἀλλὰ συμπιέζεσθαι μᾶλλον καὶ συγχωρεῖν ἕτερον ἑτέρῳ, ἕως ἂν ἔλθῃ ἐπὶ τὸ μέσον. By the earth pieces' making way for one another (συγχωρεῖν ἕτερον ἑτέρῳ) so as to be impossible for a bulge to form (οὐχ οἷόν τε κυμαίνειν) Simplicius, *In Cael.* 542.27-30 (Diels), understands their coming to occupy one another's place by ἀντιπερίστασις: τὸ οὐχ οἷόν τε κυμαίνειν εἶπεν ἀντὶ τοῦ ὑποχωρεῖν καὶ ἀντιπεριίστασθαι τῷ πλείονι τὸ ἔλαττον· τοῦτο γὰρ τὰ ὑγρὰ πάσχει, ἐπὶ δὲ τῶν τῆς γῆς μορίων πιέζεται μᾶλλον τὸ ἔλαττον ὑπὸ τοῦ μείζονος καὶ συμπλάττεται ἢ συγχωρεῖ ἕτερον ἑτέρῳ. Cf. *Phys.* 217a10-20.

16. See the previous note on *Cael.* 297a8-12.

natural motion in that the projectile's forced motion is faster than its natural motion (*Phys.* 215a14-17). Since, however, the projectile's forced motion sets off a new round of ἀντιπερίστασις in air, the projectile is forced to move further by a new part of naturally moving air which appears in the wake of the projectile as a result of the ἀντιπερίστασις. This self-sustained process lasts for as long as the forced motion of the projectile by quantities of naturally moving air is faster than its natural motion (*Phys.* 243a16-b2; Aristotle does not explain why the forced motion of the projectile gradually slows down so that its natural motion eventually asserts itself)[17]. In this light the chain of derivative contiguous movers which move the projectile according to *Phys.* 267a14-15 can be plausibly understood as the contiguous quantities of air along the trajectory of the projectile: for it is these quantities of air which, being successively displaced by the projectile as it moves along its trajectory, trigger each round of ἀντιπερίστασις and thus lead to successive quantities of naturally moving air forcing the projectile to move on.

That in *Phys.* Θ. 10 Aristotle is interested in projectile motion in so far as this forced motion bears on his argument that the prime mover cannot be a finite or an infinite material body is strongly suggested by the ἀπορία in *Phys.* 267b9-17. After his account of projectile motion (*Phys.* 266b28-267a20) Aristotle summarizes the conclusions he has reached before *Phys.* Θ. 10, i.e. that there is a primary, continuous and eternal cosmic motion which is of a single body (i.e. the sphere of the fixed stars) and is caused by an unmoved mover on the circumference of the cosmos (*Phys.* 267a21-b9). In *Phys.* 267b9-17 he then asks whether it is possible for a moving mover to cause continuous motion not (I) in the same manner as what pushes repeatedly but (II) in such a manner that the continuity of motion lies in contiguous succession[18]. For either (I′) the same moving mover must always push what is moved or pull it or both, or (II″) there must be a succession of moving movers as is the case with projectile motion where, since air is divisible, the projectile is moved by different quantities of moving air[19]. Aristotle here

17. On the account of projectile motion in *Phys.* 266b28-267a20 this motion desists (a) ὅταν ἀεὶ ἐλάττων ἡ δύναμις τοῦ κινεῖν ἐγγίγνηται τῷ ἐχομένῳ (267a8-9; τὸ ἐχόμενον is each successive quantity of air) and (b) ὅταν μηκέτι ποιήσῃ τὸ πρότερον κινοῦν, ἀλλὰ κινούμενον μόνον (267a9-10; κινοῦν and κινούμενον qualify the last quantity of air to move the projectile). (a) must implicitly lay down the threshold condition for (b) to obtain and is equivalent to the stipulation in *Phys.* 243a16-b2, for in *Phys.* 266a26-28 ἡ ἐλάττων δύναμις is defined in terms of how fast the motion or change it causes is.

18. *Phys.* 267b9-11: ἔχει δ' ἀπορίαν εἰ ἐνδέχεταί τι κινούμενον κινεῖν συνεχῶς, ἀλλὰ μὴ ὥσπερ τὸ ὠθοῦν πάλιν καὶ πάλιν, τῷ ἐφεξῆς εἶναι συνεχῶς.

19. *Phys.* 267b11-15: ἢ γὰρ αὐτὸ δεῖ ἀεὶ ὠθεῖν ἢ ἕλκειν ἢ ἄμφω, ἢ ἕτερόν τι ἐκδεχόμενον

considers two possibilities: a single moving mover causes continuous motion by pushing what is moved repeatedly or pulling it repeatedly or both (I-I′); continuous motion is due to successive moving movers and thus parallel to projectile motion (II-II″)[20]. In either case, Aristotle proceeds to argue, motion is not one but merely successive so that continuous motion can be caused only by an unmoved mover[21]. In view of his solution to the ἀπορία the single moving mover in (I-I′) as well as the chain of moving movers in (II-II″) are evidently candidates for the prime mover, which has already been shown to be unmoved as Aristotle points out in *Phys.* 267a21-b9: by answering the ἀπορία in *Phys.* 267b9-17 Aristotle not only bolsters this conclusion but also shows beyond doubt that, if the prime mover were moving, it would cause projectile motion (II-II″). Since Aristotle's refutation of (II-II″) hinges on the fact he emphasizes in his account of projectile motion at *Phys.* 266b28-267a20, namely that projectile motion is actually discontinuous[22], the purpose of this account must be to establish exactly this discontinuity and thereby rule out the hypothesis in (II-II″) that the motion caused by the prime mover is projectile motion.

Whatever might be the moving prime mover in (II-II″), it certainly cannot cause the same motion as Aristotle's unmoved prime mover, for the sphere of the fixed stars cannot be moved as if it were a projectile[23]. Nor can one assume that this moving prime mover literally causes projectile motion on the cosmic scale. For one thing, the assumption that the prime mover would cause literally projectile motion at the cosmic level if it were itself in motion

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ἄλλο παρ' ἄλλου, ὥσπερ πάλαι ἐλέχθη ἐπὶ τῶν ῥιπτουμένων, εἰ διαιρετὸς ὢν ὁ ἀὴρ [ἢ τὸ ὕδωρ] κινεῖ ἄλλος ἀεὶ κινούμενος.

20. The mover which in (I-I′) causes forced motion by simultaneously pushing and pulling what is moved causes the motion Aristotle calls δίνησις: ἡ δὲ δίνησις σύγκειται ἐξ ἕλξεώς τε καὶ ὤσεως· ἀνάγκη γὰρ τὸ δινοῦν τὸ μὲν ἕλκειν τὸ δ' ὠθεῖν· τὸ μὲν γὰρ ἀφ' αὑτοῦ τὸ δὲ πρὸς αὑτὸ ἄγει (*Phys.* 244a2-4); cf. Simplicius, *In Phys.* 1053.24-27 (Diels), and Philoponus, *In Phys.* 875.17-18 (Vitelli). δίνησις (rotation about an axis) is one of the two kinds of motion proper to a sphere (*Cael.* 290a9-10).

21. *Phys.* 267b15-16: ἀμφοτέρως δ' οὐχ οἷόν τε μίαν εἶναι, ἀλλ' ἐχομένην. μόνη ἄρα συνεχὴς ἦν κινεῖ τὸ ἀκίνητον.

22. *Phys.* 267a12-15: αὕτη μὲν οὖν ἐν τοῖς ἐνδεχομένοις ὁτὲ μὲν κινεῖσθαι ὁτὲ δ' ἠρεμεῖν ἐγγίγνεται ἡ κίνησις, καὶ οὐ συνεχής, ἀλλὰ φαίνεται· ἢ γὰρ ἐφεξῆς ὄντων ἢ ἁπτομένων ἐστίν· οὐ γὰρ ἓν τὸ κινοῦν, ἀλλ' ἐχόμενα ἀλλήλων.

23. Nor is there any reason to assume with Alexander of Aphrodisias, *apud* Simplicius, *In Phys.* 1356.33-1357.5 (Diels), that the moving mover in (II-II″) is actually the sphere of the fixed stars and, consequently, that the motion this mover causes is the motion of a planetary sphere which is carried westwards by the encompassing sphere of the fixed stars. Aristotle is clearly interested in whether continuous motion can be caused by successive moving movers, each moving the next one in the chain (cf. *Phys.* 267b11-15 quoted in n. 19), but the sphere of the fixed stars cannot be conceived as such.

is as bizarre and hard to articulate as the assumption that the sphere of the fixed stars moves as if it were a projectile. For another, the moving prime mover in (II-II″) brings about a motion which fails to qualify as the primary motion caused by the prime mover because it is discontinuous and not because it cannot be eternal. This suggests that on the hypothesis in (II-II″) the moving prime mover is tacitly assumed to cause eternal motion; if this is so, however, this motion cannot be literally projectile motion which necessarily comes to a stop. It follows that the moving prime mover in (II-II″) must cause forced motion which is not literally projectile motion but merely akin to it – in a certain fundamental way this forced motion is like the forced motion of projectiles but differs from it in that it is eternal. This eternal forced motion must be on the cosmic scale and, since it is caused by a moving mover, this mover can only be a material body. Given, therefore, the *demonstrandum* in *Phys.* Θ. 10 Aristotle must be concerned to refute (II-II″) because, if the eternal forced motion in (II-II″) is the primary cosmic motion, then the prime mover is the finite or infinite material body which brings about this eternal forced motion. Aristotle's implicit point in ruling out (II-II″) is that the prime mover cannot be this material body: if it were, it would cause a forced motion which, though eternal, is fundamentally akin to projectile motion and so cannot be the primary motion caused by the prime mover, for the primary motion must be not only eternal but also continuous and projectile motion is not continuous.

Viewed in this light, Aristotle's discussion of projectile motion in *Phys.* Θ. 10 is not primarily intended as a contribution to the understanding of this kind of forced motion. It is rather part of his argument in *Phys.* Θ. 10 to the effect that the prime mover is not only unmoved but also immaterial. That a critique of Plato is part of Aristotle's discussion of projectile motion in *Phys.* Θ. 10 helps substantiate the above, for it allows one to understand why in (II-II″) Aristotle considers the possibility that, if the primary motion in the cosmos is a forced motion akin to projectile motion but eternal, the prime mover is a moving material body, namely the body which brings about the forced motion in question. In his *Timaeus* Plato explains by ἀντιπερίστασις not only projectile motion and the complementary processes of exhalation and inhalation but also the eternal cosmic motion which is, though, not the rotation of the heavens but the constant upward and downward motion of the elements (*Tim.* 57d7-58c4). Plato assumes that there is no vacuum within the heavenly sphere and that, as a consequence, the small particles of one element rush between the larger particles of another element (*Tim.* 58a4-b5), exactly as air moves round a projectile in order for the formation of a

vacuum to be avoided[24]. However, the small particles of one element push apart the larger particles of the other element which in their turn push together the smaller particles of another element (*Tim.* 58b5-8): since there is no vacuum, the displaced large particles apparently displace the smaller particles of another element in order to occupy their places and, since the latter can only be pushed into the interstices between the large particles of any other element they find in their way thereby displacing them, the successive displacement goes on *ad infinitum*.

As a result of the ἀντιπερίστασις, quantities of all four elements move eternally upwards and downwards away from and back to their proper places (*Tim.* 58b8-c4) thus making possible the transformation of one element into another, a process which Plato likens to a circle (*Tim.* 49b7-c7)[25]. Like Aristotle, Plato assumes that elemental change is contingent on a quantity of one element (e.g. water) encountering a quantity of another element (e.g. fire). As a result of this encounter, the quantity of one element is displaced or «divided» (*Tim.* 56d1-e1), i.e. the particles of this element are broken down by the particles of the other element into their triangular atomic components: the latter «settle» (cf. *Tim.* 56d7, e5, 57a2, b1-2) or recombine (cf. *Tim.* 56d4-5) into the smaller particles of the «winning» element (cf. *Tim.* 57b2) but Plato also envisages the possibility that some large particles of the «losing» element are simply forced to move away by the impact (cf. *Tim.* 57a7-b7) toward their proper place[26]. The ἀντιπερίστασις explains how a quantity of one element can encounter and thus act on a quantity of another element. If the formation of a vacuum is to be prevented, the small particles of e.g. fire must crowd into the interstices between the larger particles of e.g. water which are thus pushed apart and displaced or break down into their triangular atomic components: since, however, the displaced large particles can only displace any finer particles of other elements they meet, they push

24. In *Cael.* 306b3-9 Aristotle objects that Plato's universe cannot be a plenum because, although Plato assigns the cube and the pyramid, the only solids which can fill up a place without leaving interstices, to the particles of earth and fire respectively, he must assign two other regular polyhedra (the octahedron and icosahedron) to the particles of air and water. Cf. A. E. Taylor, *A Commentary on Plato's Timaeus*, Oxford 1928, p. 399: «a *spherical* region cannot be completely filled up with rectilinear solids of any kind, unless you are prepared to suppose that there is an infinite range of different sizes of them from some finite magnitude down to the actually infinitesimal». For Taylor Plato's claim that there is no vacuum within the heavens should not be taken too literally. See also L. Brisson & F. W. Meyerstein, *Inventing the Universe: Plato's* Timaeus, *the Big Bang and the Problem of Scientific Knowledge*, Albany, NY 1995, pp. 55-56.

25. Cf. the comparison of respiration, which is necessitated by the absence of vacuum and is thus also explained via ἀντιπερίστασις, with a turning wheel in *Tim.* 79b7-c1.

26. For illustrative examples of Timaean elemental transformations see G. Vlastos, *Plato's Universe*, Oxford 1975, pp. 70-72.

these finer particles together and either force them to recombine into their own form or simply displace them (*Tim.* 57a7-b7) so that the processes of ἀντιπερίστασις and the concomitant elemental transformation go on *ad infinitum*.

Thus the ἀντιπερίστασις allows Plato to explain not only projectile motion but also the eternal motion on the cosmic scale. Since, therefore, Aristotle's account of projectile motion at *Phys.* 266b28-267a20 is couched as a critique of a rival explanation of this motion via ἀντιπερίστασις, it stands to reason that he is interested in projectile motion only inasmuch as projectile motion is of the same type as the forced motion whose explanation by means of ἀντιπερίστασις constitutes for Plato a satisfactory answer to the question why there is eternal motion on the cosmic scale; since Aristotle tackles the same question in *Phys.* Θ, this is exactly what one would expect to be the case with a critique of Plato's ἀντιπερίστασις in this treatise. It cannot, however, be accidental that the refutation of the hypothesis in (II-II″) is grounded in the account of projectile motion at *Phys.* 266b28-267a20 and that, as seen above, on this hypothesis the primary motion caused by the prime mover is a forced motion akin to projectile motion but eternal: if, therefore, the eternal forced motion in (II-II″) is, as is plausible to assume, the same as the eternal forced motion whose explanation amounts by Plato's lights to a satisfactory account of the eternal motion on the cosmic scale, the material prime mover in (II-II″) brings about the eternal forced motion of the sublunary elements in Aristotelian terms. Now the forced motion of the sublunary elements is akin to projectile motion for Aristotle too and, if its explanation sufficed to account for the eternal motion on the cosmic scale, as Plato thinks, the primary motion caused by the prime mover would be this forced motion, not the rotation of a heavenly sphere as Aristotle takes it: in this case, however, Aristotle could identify the prime mover with the finite material body which causes the eternal forced motion of the sublunary elements.

In order to show that locomotion is prior to, or a necessary condition for, growth and qualitative change Aristotle argues in *Phys.* Θ. 7 that growth presupposes qualitative change, for it is in effect the change of one of two contraries into the other and thus for everything that changes qualitatively there must be what causes this change and turns e.g. something potentially hot into actually hot[27]. Viewed in the broadest terms, as is appropriate in a cosmo-

27. *Phys.* 260a29-b2: ἀδύνατον γὰρ αὔξησιν εἶναι ἀλλοιώσεως μὴ προϋπαρχούσης· τὸ γὰρ αὐξανόμενον ἔστιν μὲν ὡς ὁμοίῳ αὐξάνεται, ἔστιν δ' ὡς ἀνομοίῳ· τροφὴ γὰρ λέγεται τῷ ἐναντίῳ τὸ ἐναντίον. προσγίγνεται δὲ πᾶν γιγνόμενον ὅμοιον ὁμοίῳ. ἀνάγκη οὖν ἀλλοίωσιν εἶναι τὴν εἰς τἀναντία μεταβολήν. ἀλλὰ μὴν εἴ γε ἀλλοιοῦται, δεῖ τι εἶναι τὸ ἀλλοι-

logical context, Aristotle's example is a case of elemental transformation (cf. *DA* 416a21-29), the ultimate cause of qualitative change in the sublunary sphere: a quantity of earth, which is potentially hot and thus actually cold, turns into fire, which is actually hot, if acted upon by a quantity of fire which increases as a result of the elemental transformation[28]. Since, therefore, Aristotle argues that locomotion is a necessary condition for the transformation of earth into fire because an actually hot agent must approach the potentially hot patient in order to affect it[29], the locomotion in question can only be rectilinear natural motion[30]. For one of the two ways in which heat

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οὖν καὶ ποιοῦν ἐκ τοῦ δυνάμει θερμοῦ ἐνεργείᾳ θερμόν (text continues in n. 29). «Growth presupposes qualitative change which makes assimilation of food possible» (Graham [above, n. 2], p. 121; cf. *DA* 416a21ff.) and in reducing growth to qualitative change brought about by the action of the hot Aristotle presupposes his doctrine that fire is a «co-cause» in nutrition (*DA* 416a9-18, *GA* 740b29-33; on these passages see G. Freudenthal, *Aristotle's Theory of Material Substance*, Oxford 1995, pp. 29-34).

28. Cf. the conclusion of Aristotle's account of the first mechanism of elemental transformation in *GC* 2.4: καὶ πάλιν ἐπεὶ τὸ μὲν πῦρ ξηρὸν καὶ θερμόν, ἡ δὲ γῆ ψυχρὸν καὶ ξηρόν, ἐὰν φθαρῇ τὸ ψυχρόν, πῦρ ἔσται ἐκ γῆς (331a36-b2). The destruction of one contrary by the other means that the destroyed contrary has turned into the contrary which acted on it and thus that each contrary is in potentiality the other; cf. *GC* 334b20-26: ἔστι γὰρ τὸ ἐνεργείᾳ θερμὸν δυνάμει ψυχρὸν καὶ τὸ ἐνεργείᾳ ψυχρὸν δυνάμει θερμόν, ὥστε [...] μεταβάλλει εἰς ἄλληλα· ὁμοίως δὲ καὶ ἐπὶ τῶν ἄλλων ἐναντίων. Καὶ πρῶτον οὕτω τὰ στοιχεῖα μεταβάλλει, ἐκ δὲ τούτων σάρκες καὶ ὀστᾶ καὶ τὰ τοιαῦτα, τοῦ μὲν θερμοῦ γινομένου ψυχροῦ, τοῦ δὲ ψυχροῦ θερμοῦ [...].

29. *Phys.* 260b2-7: δῆλον οὖν ὅτι τὸ κινοῦν οὐχ ὁμοίως ἔχει, ἀλλ' ὁτὲ μὲν ἐγγύτερον ὁτὲ δὲ πορρώτερον τοῦ ἀλλοιουμένου ἐστίν. ταῦτα δ' ἄνευ φορᾶς οὐκ ἐνδέχεται ὑπάρχειν. εἰ ἄρα ἀνάγκη ἀεὶ κίνησιν εἶναι, ἀνάγκη καὶ φορὰν ἀεὶ εἶναι πρώτην τῶν κινήσεων, καὶ φορᾶς, εἰ ἔστιν ἡ μὲν πρώτη ἡ δ' ὑστέρα, τὴν πρώτην.

30. In his comments on *Phys.* 260b2-7 Simplicius, *In Phys.*1265.36-1266.2 (Diels), assumes that the locomotion Aristotle has in mind is the motion of the food which must be moved in order to be digested. Since Aristotle does assume that nourishment comes from the dry and the wet when these are acted upon by the natural source of heat in the stomach (*PA* 650a3ff.), there is no doubt that nourishment and thus growth presupposes the motion of food toward the innate heat of the stomach. It is, however, unlikely that this is the motion which in *Phys.* 260b2-7 is argued to be prior to qualitative change. Aristotle attempts to show that locomotion is prior to qualitative change *per se* but this general claim cannot be established by first reducing growth to qualitative change and then pointing out that growth *qua* qualitative change presupposes the motion of food toward the digestive tract. The generality of Aristotle's argument is better served if in *Phys.* 260b2-7 the affective source of heat which is sometimes closer to, and sometimes farther from, what is to be changed is the sun: for one of the two causes of the constant qualitative change, i.e. elemental transformation, in the sublunary sphere is the annual motion of the sun in the ecliptic whose inclination causes the distance between the sun and a given locus of qualitative change to vary around the year (the other cause is the rotation of the heavens; *GC* 336a31-b9, 337a7-15). If this is so, however, then it is circular locomotion (the annual motion of the sun in the ecliptic or the rotation of the heavens) which in *Phys.* 260b2-7 is shown to be prior to qualitative change and thus Aristotle's point in this passage concerns only the type of locomotion which, as will turn out, is primary whereas Aristotle explicitly establishes the priority of locomotion in general, irrespective of whether a type of locomotion will turn out to be

reaches, and thus interacts with, earth is the forced motion of fire away from the periphery of the sublunary sphere: quantities of fire are dislocated from their natural place by the rapid rotation of the heavens and, thrust into air, are forced to move downwards (*Meteor.* 341a28-31: διά τε ταύτην οὖν τὴν αἰτίαν ἀφικνεῖται πρὸς τόνδε τὸν τόπον ἡ θερμότης, καὶ διὰ τὸ τὸ περιέχον πῦρ τὸν ἀέρα διαρραίνεσθαι τῇ κινήσει πολλάκις καὶ φέρεσθαι βίᾳ κάτω) but this forced motion is explained by the rectilinear natural motion of the air. Alexander (*In Meteor.* 17.26-30 [Hayduck]) notes that, if heat is transmitted to the Earth by the fire which is forced to move from its natural place, air becomes a «moving cause of heat for fire» ([...] τὸ περιέχον πῦρ [...] ὑπὸ τῆς ἐγκυκλίου τῶν ἄστρων κινήσεως πολλάκις διακρίνεταί τε καὶ φέρεται βίᾳ κάτω, ἔνθα ὁ ἀήρ, καὶ φερόμενον θερμότητος αἴτιον αὐτῷ γίνεται). The other way by which heat is transmitted to the Earth does not presuppose air as a «moving cause» – air functions simply as the medium through which the heat generated by the rapid daily motion of the sun flows to the Earth (Alexander, *In Meteor.* 17.18-25 [Hayduck]). If, however, heat is transmitted by masses of fire forced from their natural place into the lower stratum of air, then air is indeed a «moving cause of heat», as Alexander puts it, for on *Cael.* 3.2 the forced motion of an element is caused by the natural motion of air. As air can force a piece of earth to move upwards in virtue of its moving naturally upwards, it can also force a mass of fire to move downwards in virtue of its moving naturally downwards as well.

Since now in Aristotle's sublunary sphere water constantly changes into air, air into fire and finally fire into water (*GC* 337a4-6), quantities of fire must constantly act upon some air or be acted upon by some water but this can be so only if quantities of fire are constantly displaced from their natural place so as to come in contact with either air or water which is accumulated on the surface of the Earth (cf. *Meteor.* 340a7-8)[31]. If, however, quantities of fire are constantly forced to move downwards, on the *Cael.* 3.2 account of forced motion numerically distinct chains of contiguous air masses must be constantly in natural motion. Now for Aristotle the changeable sublunary

primary. In this light the secondary type of locomotion, i.e. rectilinear natural locomotion which along with circular locomotion is indeed presupposed by qualitative change, must also be prior to qualitative change.

31. Air is transformed into fire by the first of the three mechanisms of elemental change described in *GC* 3.2: [...] ἐκ πυρὸς μὲν ἔσται ἀὴρ θατέρου μεταβάλλοντος (τὸ μὲν γὰρ ἦν θερμὸν καὶ ξηρόν, τὸ δὲ θερμὸν καὶ ὑγρόν, ὥστε ἂν κρατηθῇ τὸ ξηρὸν ὑπὸ τοῦ ὑγροῦ, ἀὴρ ἔσται) [...] (331a26-29). Fire is changed into water by the second mechanism: ἀνάγκη γάρ, εἰ ἔσται ἐξ ὕδατος πῦρ, φθαρῆναι καὶ τὸ ψυχρὸν καὶ τὸ ὑγρόν, καὶ πάλιν εἰ ἐκ γῆς ἀήρ, φθαρῆναι καὶ τὸ ψυχρὸν καὶ τὸ ξηρόν. Ὡσαύτως δὲ καὶ εἰ ἐκ πυρὸς καὶ ἀέρος ὕδωρ καὶ γῆ, ἀνάγκη ἀμφότερα μεταβάλλειν. Αὕτη μὲν οὖν χρονιωτέρα ἡ γένεσις (*GC* 331b7-11).

elements imitate the changeless celestial bodies in that they are always active (*Met.* 1050b22-30) and, since the eternal activity of the celestial bodies is their circular motion, i.e. the natural motion of the *aether*, the eternal activity of the sublunary elements must also be their natural motion[32]. Air is of course always in natural motion not because the entire quantity of this element in the sublunary sphere always moves naturally but because at any given time numerically distinct quantities of air, which is produced by the transformation of e.g. some water or earth into air, perform individuated but temporally bounded natural motions[33]. It is in this sense that air is not in any fixed place as it is constantly transformed into other elements under the influence of the sun's twofold circular motion (*GC* 337a7-15); Aristotle cannot imply that the entire quantity of air moves constantly to and away from its natural place (or, equivalently, that the entire quantity of air is periodically transformed into other elements). Thus the total quantity of air in the sublunary sphere imitates the eternal activity of the celestial bodies in that numerically distinct parts of this quantity are constantly in natural motion which is thus not only eternal but also continuous in the derivative sense that it imitates the continuous circular motion of the celestial bodies (*GC* 337a6-7). Since, however, it is this eternal and derivatively continuous activity of air, i.e. its natural motion, that also causes the eternal forced motion of the other elements, the finite quantity of air in the sublunary sphere brings about this eternal forced motion in the sense that numerically distinct parts of this quantity, finite both in size and number, constantly cause individuated but temporally bounded forced motions.

The hypothesis Aristotle refutes in (II-II″) can thus be recovered from

32. Cf. M. L. Gill, *Aristotle on Substance: The Paradox of Unity*, Oxford 1989, p. 235. For W. D. Ross, *Aristotle's Metaphysics*, Oxford 1924, pp. 265-266, it is unclear whether the eternal activity of the sublunary elements «refers to the natural movement of fire upwards, and of earth downwards, or to the constant tendency of the elements to change into one another, by virtue of which Aristotle says (*De Gen et Corr.* 337a1-7) they imitate the circular movement of the heavenly bodies»; the second alternative is adopted by M. F. Burnyeat et al., *Notes on Book Zeta of Aristotle's Metaphysics*, Oxford 1979, p. 145. There are, however, not two genuine alternatives here because for Aristotle the transformation of e.g. water into air entails the natural motion of air, unless something prevents it: τὸ γὰρ κοῦφον γίγνεται ἐκ βαρέος, οἷον ἐξ ὕδατος ἀὴρ (τοῦτο γὰρ δυνάμει πρῶτον), καὶ ἤδη κοῦφον, καὶ ἐνεργήσει γ' εὐθύς, ἂν μή τι κωλύῃ. ἐνέργεια δὲ τοῦ κούφου τὸ ποὺ εἶναι καὶ ἄνω, κωλύεται δ', ὅταν ἐν τῷ ἐναντίῳ τόπῳ ᾖ (*Phys.* 255b8-12).

33. Cf. *Phys.* 255b8-12, quoted in the previous note. For Aristotle a quantity of water and the quantity of air it yields are specifically but not numerically the same (*GC* 338b14-18) and, since he also posits that two quantities of water from the same fountain are only specifically the same though strikingly similar (*Top.* 104a14-24), the quantities of air which at any given time are produced by elemental transformation in the sublunary sphere are numerically distinct; for the Aristotelian elements as proper particulars (τόδε τι) see Gill (above, n. 32), p. 84.

Plato's explanation of the eternal motion on the cosmic scale: if one explains the eternal motion at the cosmic level by accounting not for the rotation of a heavenly sphere but for the forced motion of the sublunary elements as Plato does, Aristotle can reach the conclusion that the prime mover, which is responsible for the primary cosmic motion to be accounted for, is a moving and finite material body (namely the finite quantity of air in the sublunary sphere). What is more, Plato's account of the eternal motion on the cosmic scale entails by Aristotle's lights that the prime mover is a finite material body which causes eternal motion in virtue of its different parts constantly causing individuated but temporally bounded motions – it is not the case that the *entire* material body in question acts constantly on what is moved. Aristotle, however, concludes that the prime mover, which by definition causes eternal motion, cannot be a finite material body because he has shown in (a) that no such body can cause eternal motion but (a) clearly holds only for entire material bodies acting constantly on what is moved (see *Phys.* 266a21-22). Ruling out (II-II″) is, therefore, tightly woven into the cosmological argument in *Phys.* Θ. 10: for, if Aristotle is to conclude that the prime mover cannot be a finite material body, he must not only rely on (a) but also refute the hypothesis in (II-II″) – a finite material body is the prime mover because it does cause eternal motion in that different parts of it constantly cause individuated but temporally bounded motions. Since the account of projectile motion spearheads Aristotle's refutation of the hypothesis in (II-II″), this account is also an integral part of the cosmological argument in *Phys.* Θ. 10 and is motivated by the fact that for Aristotle this hypothesis is raised by Plato's account of the eternal motion on the cosmic scale. What Plato accounts for is the eternal forced motion of Aristotle's sublunary elements which, by Plato's lights as well as by Aristotle's, is of the same type as the forced motion of projectiles: thus the implication of Plato's account which threatens Aristotle's conclusion in *Phys.* Θ. 10 can be defused via the correct explanation of this forced motion.

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