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ARISTOTLE ON CONTINUITY: CONTINUOUS CONNECTION IN *PHYS.* V 3 AND THE MATHEMATICAL ACCOUNT OF MOTION AND TIME IN *PHYS.* VI

Abstract

Wholes have parts, and wholes are prior to parts according to Aristotle. Aristotle's accounts of continuity, in *Phys.* V 3 (plus sections in *Metaph.* Δ 6 and I 1) on the one hand and in *Phys*. VI on the other, are specified in terms of ways in which wholes are related to parts. The *synthesis* account in *Phys.* V 3 etc. applies primarily to bodies (in, e.g., anatomy). It indicates a variety of ways in which parts of a body are kept together by a common boundary and are thereby combined into a mostly inhomogeneous, functional whole. Only the *analysis* account in *Phys*. VI applies primarily to linear continua such as movements, paths of movements, and time. The structure it indicates is only superficially described as indefinite divisibility: what matters is the transfer of potential divisions from path to movement and time (and conversely) which, surprisingly, requires an equivalent to Dedekind's continuity principle to be tacitly presupposed. – In the present paper, my agenda will focus on the exposition of the relevant theories offered by Aristotle in *Phys*. V 3 and *Phys*. VI 1-2, respectively, with a view to the applications envisaged by Aristotle and to the mathematics involved.

Keywords

Continuity, Motion and Time, Dedekind's Continuity Principle, Homogeneous and Inhomogeneous Bodies

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1. Introduction[*]

Aristotle offers two accounts of continuity. The *synthesis* account in *Phys.* V 3 (plus sections in *Metaph.* Δ 6 and I 1) indicates a variety of ways in which parts of a body are kept together by a common boundary and are thereby combined into a mostly inhomogeneous, functional whole. Only the *analysis* account in *Phys*. VI applies primarily to linear continua such as movements, paths of movements, and time.

For limitations of space, I will confine my exposition to what I think are the essentials of the theories offered by Aristotle in *Phys*. V 3 and in *Phys*. VI 1-2 (up to 233a12, leaving aside the subsequent "traditionalist" rest of the chapter). The backlink at the beginning of *Phys*. VI (see T19 below) suggests that ch. VI 1 is in a way based on ch. V 3 and, in turn, the latter chapter is meant to provide a basis for the argument in the former. I will argue that this is misleading. On the one hand, the teleological reading implied turns out to be an impediment to understanding that chapter in its own terms and, particularly, to make sense of its metaphors and examples. Neither is the account of continuity in *Phys*. V 3, taken by itself, about motion, nor does the chapter offer any hint at the transfer to motion which occurs only later in *Phys*. V 4 (see T9 and T10 below) and subsequently in *Phys*. VI. On the other hand, *Phys*. VI 1 is only superficially linked to *Phys*. V 3. The definition therefrom transferred fails to explain what, in the first theorem of *Phys* VI 1, "a continuum" is and what, therefore, the subsequent argument is about (see section 4.1 below). The analysis of *Phys*. VI 1-2 requires a method different from my method in the study of *Phys*. V 3. My leading question concerning *Phys*. VI 1-2 is, How to get the mathematics right? That is to say, I seek a sound mathematical argument which, I assume, the text indicates (see also section 4.2 below).

Of Aristotle's two definitions of continuity, one is in terms of **divi**sion (T1), the other in terms of **conn**ection (T2).

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T1. (Df. **Divi**) I call continuous what is divisible into again and again divisibles.
(*Phys*. VI 2.232b24-25: λέγω δὲ συνεχὲς τὸ | διαιρετὸν εἰς αἰεὶ διαιρετά)

T2. (Df. **Conn**) Continuous[ly connected] are items of which the extremities are one; and in contact are items of which [the extremities] are together.
(*Phys*. VI 1.231a22-23: συνεχῆ μὲν ὧν τὰ ἔσχατα ἕν, ἁπτὸ|μενα δ' ὧν ἅμα.)

Note that 'continuous' is a one-place predicate according to **Divi**, but a two-place predicate (i.e., a relation) according to **Conn**.[1] Correspondingly, in Aristotle's account of motion, **Divi** is a matter of analysis, **Conn** of synthesis.

I will argue that

- Sections 2 and 3: As defined in *Phys*. V 3 (and in *Metaph*. Δ 6 and I 1), **Conn** pertains primarily to the connection of bodies, and is only later transferred to motion in passages of *Phys*. V 4 (with applications in *Phys*. VIII) and of VI 1.

- Section 4.1: In the first part of *Phys*. VI 1 (231a21-b18), Aristotle points out that division into continuously connected parts never comes to an end and that, therefore **Divi** can be derived from **Conn** in a way. Lacking starting points, **Conn** fails to account for the structure of linear continua in terms of synthesis, whereas **Divi** does in terms of analysis.

- Sections 4.2 and 4.3: According to **Divi,** the potential divisions of linear continua are dense. But in addition to **Divi**, crucial features in Aristotle's account are (i) the isomorphism established by straightforward motion between path, and movement, and time, and (ii) a continuity principle which secures that the isomorphism is not just part by part (as required by the argument in the second part of *Phys*. VI 1.231b18-232a22), but limit by limit (as required by the argument in the first part of *Phys*. VI 2 (232a23-233a12).

[1] Cf. Sattler (2020) pp. 295-6, (2021) p. 16. Similarly, Glasner (2020) p. 29 (see below 3.1.3).

2. Areas of Application

2.1. Divi

Standard applications of **Divi** belong to the mathematical account of motion offered in *Phys*.VI (see below section 4) and are adumbrated in the preliminaries to *Phys*. III 1. Motion traverses a path during a period of time. According to *Phys*. IV 11, both linear order and continuity transfer from the path to the motion, and from the motion to time. The same isomorphism is described in *Phys*. VI 1 (T26) and applied throughout *Phys*. VI. That **Divi** holds of magnitudes and, in particular, of the path of a movement, is implied at the beginning of *Phys*. VI 2. For, assuming that

T3. every magnitude is divisible into magnitudes,[2]

the magnitudes into which a magnitude is divided are again divisible, which is enough for **Divi** to hold. At the beginning of *Phys*. III 1, **Divi** is mentioned as a commonly assumed mark of continuity,[3] and applied to motion. That **Divi** holds of time, is the outcome of the refined isomorphism argument in *Phys*. VI 2,[4] on which see section 4.3 below.

As another candidate, homogeneous stuffs and bodies (*homoiomerē*) suggest themselves. But as far as I can see, continuity of bodies is rather described by Aristotle in terms of **Conn**. There may be also a concern about minima naturalia.[5] That body in general is indefinitely divisible belongs to its having magnitude and is, therefore, just another application of T3.

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[2] *Phys*. VI 12.232a23: πᾶν μέγεθος εἰς μεγέθη διαιρετόν.

[3] *Phys*. III 1.200b18-20: "... those who try to define the continuous often find themselves making use of the definition of the infinite as an auxiliary, the supposition being that what is divisible ad infinitum is continuous." (... τοῖς ὁριζομένοις τὸ συνεχὲς συμ|βαίνει προσχρήσασθαι πολλάκις τῷ λόγῳ τῷ τοῦ ἀπείρου, | ὡς τὸ εἰς ἄπειρον διαιρετὸν συνεχὲς ὄν, tr. Hussey).

[4] *Phys*. VI 2.232b24-26: "... it is necessary that time, too, is continuous. I call continuous what is divisible into again and again divisibles. On the basis of this [account of the] continuous, it is necessary that time is continuous." (... ἀνάγκη καὶ τὸν χρόνον συνεχῆ εἶναι. λέγω δὲ συνεχὲς τὸ | διαιρετὸν εἰς αἰεὶ διαιρετά· τούτου γὰρ ὑποκειμένου τοῦ συνε|χοῦς, ἀνάγκη συνεχῆ εἶναι τὸν χρόνον.

[5] See my note on *Phys*. I 4.187b13-188a2 in Heinemann (2021) pp. 219-21.

2.2. Conn

In a way, the distinction between contact and continuity applies to Aristotle's account of place. In *Phys*. IV 4, place is defined in terms of contact. Extremities being just together, the edge of the surrounding body is what the body surrounded is primarily in, i.e., its place. By contrast, bodies which are continuously connected so as to form a homogeneous whole are not distinguished by place but only as parts:

T4. So when that which surrounds is not divided from, but continuous with, [the thing surrounded], the latter is said to be in the former not as in a place but as the part is in the whole; but when that which surrounds is divided from and in contact with [the thing surrounded], the latter is in the extreme of the surrounding thing primarily {i.e., as in its primary place (GH)}; and this extreme is neither a part of that which is in it, nor is it greater than the extension [of the thing surrounded] but equal to it, since the extremes of things which are in contact are in the same [spot].[6]

Aristotle's claim that, in the latter case, the parts are potentially in a place

T5. ... when a homogeneous thing is continuous, the parts are potentially in place; when, by contrast, they are separate but in contact, as in a heap, they are actually so[7]

must be qualified. If a homogeneous body is continuous, there is nothing internal to the body to mark off a part of it. Hence, there is no question of given parts being potentially in a place but, rather, of there being potential parts which, when specified in an appropriate way, may be also attributed places. In his account of the formation of hailstones, Aristotle explains that, in clouds, small portions of water join to form raindrops, but hailstones cannot come to be analogously since

[6] *Phys*. IV 4.211b29-34: ὅταν μὲν οὖν μὴ διῃρημένον ᾖ τὸ περιέχον ἀλλὰ | συνεχές, οὐχ ὡς ἐν τόπῳ λέγεται εἶναι ἐν ἐκείνῳ, ἀλλ' | ὡς μέρος ἐν ὅλῳ· ὅταν δὲ διῃρημένον ᾖ καὶ ἁπτόμενον, ἐν | πρώτῳ ἐστὶ τῷ ἐσχάτῳ τοῦ περιέχοντος, ὃ οὔτε ἐστὶ μέρος | τοῦ ἐν αὐτῷ οὔτε μεῖζον τοῦ διαστήματος ἀλλ' ἴσον· ἐν | γὰρ τῷ αὐτῷ τὰ ἔσχατα τῶν ἁπτομένων (tr. Hussey, modified).
[7] *Phys*. IV 5.212b4-6: ὅταν μὲν | συνεχὲς ᾖ τὸ ὁμοιομερές, κατὰ δύναμιν ἐν τόπῳ τὰ μέρη, | ὅταν δὲ χωρισθῇ μὲν ἅπτηται δ' ὥσπερ σωρός, κατ' ἐνέργειαν (tr. Hussey, modified).

T6. frozen [bodies] do not grow together like liquids.[8]

When drops of water merge and a bigger drop comes into being, there is no way to trace back part of the latter to one of the former – unless a difference in contamination or quality is retained in the fusion, which is not generally the case. As a consequence, there seems to be an obstacle to the application of **Conn** since, on the one hand, **Conn** suggests that a common boundary of continuously connected bodies persist whereas, on the other hand, boundaries vanish when portions of fluid stuff merge.[9]

In a way, the claims by Furley and White, approvingly quoted by Glasner (2020, p. 30 n. 99), are therefore misleading. Furley (1982, p. 30) claims that Aristotle, when discussing continuous connection,

> thinks primarily of homogenous natural substances, such as air and water. The distinction between *in contact* and *continuous* is primarily to distinguish a case such as the junction of the upper surface of the sea with the lower surface of the air from the junction of two bodies of water.

White (1992, p. 27) agrees, adding that, as T5 makes it explicit,

> continuity pertains to what is homoeomerous, while contiguity pertains to parts which are spatially joined but essentially different.

[8] *Meteor*. I 12.348a12-13: … οὐ γὰρ συμφύεται τὰ | πεπηγότα ὥσπερ τὰ ὑγρά. – Note that "growing together" (*sumphusis*) = continuous connection at *Phys*. V 3.227a23-27 (T16 below).

[9] I thus agree with Katz who (2021, p. 255 *contra* Pfeiffer 2017, pp. 178 ff.) also denies that, when fluids merge, boundaries persist who according to Aristotle. But I do not agree with the explanation she adduces from Aristotle. As far as I can see, his explanation derives from the characteristic way moist stuffs adapt their limits to the body which is around (*GC* II 2.329b29-330a1): if both bodies are moist, the common limit is blurred. By contrast, Katz adduces another characteristic: that, under pressure, liquids do not decrease but recede (*GC* II 2.330a8-9 and *Meteor*. IV 4.382a11-14). I do not see how the blurring of the boundaries is thereby achieved. Clearly, this cannot be the whole story since even for a fully homogeneous liquid there is a difference between, e.g., rotation and rest. But I doubt that Aristotle can account for this difference in terms of boundaries (and, hence, places) of parts. (I am grateful to my anonymous reader who urged me to make this explicit.)

Glasner (*loc. cit.*) mentions "two celestial spheres" as an example of "two distinct objects" which "cannot be continuous", but "can be contiguous." This suggests that White's link of contiguity with essential difference is confined to fluids (such as water and air), whereas solids of the same kind may be either contiguous or continuously connected. It should be added that the language employed in *Phys*. V 3 and in the parallel passages in Δ 4 and 6 also suggests that, in general, continuously connected components are different in quality and may be even different in kind, key examples being taken from animal parts (see sect. 3.1.4 below). In particular, Aristotle's account of continuity in *Phys*. V 3 is consistent with the doctrine in *Metaph.* Δ 6 and I 1 that kinematic unity is the mark of continuous connection (T17 and T18, see below section 3.2). By contrast, Aristotle's account of place in *Phys*. IV 1-5 does not seem to provide the best examples of the distinction indicated by **Conn**.[10]

There are obvious applications of **Conn** to time: periods of time are continuously connected at instants. Instants follow the pattern of a point which

T7. keeps the length together and marks it off; for it is the beginning of one part and the end of another.[11]

Hence,

T8. the now is the connectedness of time, ... for it connects the past and future time, and is a limit of time, since it is the beginning of one and the end of the other.[12]

Further, successive movements may be continuously connected or not, see, e.g.,

T9. Since every movement is continuous, a movement that is unconditionally one must (if indeed every movement is divisible) be continuous, and a continuous movement must be one. For not every movement could become continuous[ly connected] with every other

[10] See also section 3.1.1 concerning an inconsistency which suggests that *Phys*. IV 1-5 must not be taken as presupposed in *Phys*. V 3.

[11] *Phys*. IV 11.220a10-11: ... συνέχει | τὸ μῆκος καὶ ὁρίζει· ἔστι γὰρ τοῦ μὲν ἀρχὴ τοῦ δὲ τελευτή.

[12] *Phys*. IV 13.222a10-12: τὸ δὲ νῦν ἐστιν συνέχεια χρόνου ... · συνέχει | γὰρ τὸν χρόνον τὸν παρεληλυθότα καὶ ἐσόμενον, καὶ | ὅλως πέρας χρόνου ἐστίν· ἔστι γὰρ τοῦ μὲν ἀρχή, τοῦ δὲ τελευτή. (tr. Hussey, modified). – See also Strobach (forthcoming) on bar lines in musical notation.

movement, any more than a random thing with any other random thing, but rather those in which the extremities are one. [13]

and

T10. It has been established [in *Phys*. V 3, GH] that items are continuous[ly connected] of which the extremities are one. So, movements are contiguous and successive in virtue of time being continuous, but [time is something] continuous in virtue of the movements being continuous, and this is when the extremity becomes one for both. That is why a movement that is unconditionally continuous and one must be the same in species, of one thing, and in one time.[14]

In particular, since eternal motion must be periodic, turning from one intermediate position to another and back, it is a requirement of its unity that every recurrent section is continuously connected with its immediately successor.[15]

Doubtlessly, **Conn** does apply to linear continua such as path, motion, and time. But I will argue, *first*, that linear continua are alien to Aristotle's

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[13] *Phys*. V 4.228a20-24: ἐπεὶ δὲ συνεχὴς πᾶσα κίνησις, τήν τε ἁπλῶς | μίαν ἀνάγκη καὶ συνεχῆ εἶναι, εἴπερ πᾶσα διαιρετή, καὶ | εἰ συνεχής, μίαν. οὐ γὰρ πᾶσα γένοιτ' ἂν συνεχὴς πάσῃ, | ὥσπερ οὐδ' ἄλλο οὐδὲν τῷ τυχόντι τὸ τυχόν, ἀλλ' ὅσων ἓν | τὰ ἔσχατα (tr. Reeve, modified).

[14] *Phys*. V 4.228a29-b3: κεῖται γὰρ τὸ συνεχές, ὧν | τὰ ἔσχατα ἕν. ὥστ' ἐχόμεναι καὶ ἐφεξῆς εἰσὶ τῷ τὸν χρό|νον εἶναι συνεχῆ, συνεχὲς δὲ τῷ τὰς κινήσεις· τοῦτο δ', | ὅταν ἓν τὸ ἔσχατον γένηται ἀμφοῖν. διὸ ἀνάγκη τὴν αὐτὴν | εἶναι τῷ εἴδει καὶ ἑνὸς καὶ ἐν ἑνὶ χρόνῳ τὴν ἁπλῶς συνεχῆ | κίνησιν καὶ μίαν ... – text at a31: Pellegrin (2002) p. 293 n. 2 (tr. Reeve, modified).

[15] *Phys*. VIII 6.259a15-20: "... it has been demonstrated that there must always be motion. But if always, it must be continuous, for what is everlasting is continuous, while what is successive is not continuous. But if continuous, it is one. But motion is one if it is the by one mover and of one moved thing. For if now one thing is the mover, and now another, the whole movement will not be continuous but successive." (δὲδεικται γὰρ ὅτι ἀνάγκη ἀεὶ κίνησιν εἶναι. | εἰ δὲ ἀεί, ἀνάγκη συνεχῆ εἶναι· καὶ γὰρ τὸ ἀεὶ συνε|χές, τὸ δ' ἐφεξῆς οὐ συνεχές. ἀλλὰ μὴν εἴ γε συνεχής, | μία. μία δ' ἡ ὑφ' ἑνός τε τοῦ κινοῦντος καὶ ἑνὸς τοῦ κινου|μένου· εἰ γὰρ ἄλλο καὶ ἄλλο κινήσει, οὐ συνεχὴς ἡ | ὅλη κίνησις, ἀλλ' ἐφεξῆς – tr. Graham, modified). *Phys*. VIII 8.261b31-262a5: "Clearly, what travels with a straight and bounded motion does not travel continuously. For it turns back, and what turns back on a straight line undergoes contrary motions. ...We have already determined what is the single and continuous motion, that it is the motion of a single subject in a single time and in respect to an indistinguishable form... Contraries differ in form and are not one." (ὅτι δὲ τὸ φερόμενον τὴν εὐθεῖαν καὶ | πεπερασμένην οὐ φέρεται συνεχῶς, δῆλον· ἀνακάμπτει | γάρ, τὸ δ' ἀνακάμπτον τὴν εὐθεῖαν τὰς ἐναντίας κινεῖται | κινήσεις· ... (b36) τίς δ' ἐστὶν ἡ μία καὶ |(a1) συνεχὴς κίνησις, διώρισται πρότερον, ὅτι ἡ τοῦ ἑνὸς καὶ ἐν | ἑνὶ χρόνῳ καὶ ἐν ἀδιαφόρῳ κατ' εἶδος...(a5) τὰ δ' ἐναντία διαφέρει τῷ εἴδει, καὶ οὐχ ἕν – tr. Graham, modified).

account of continuous connection in *Phys*. V 3 and, *second*, that for the mathematical account of the linear continua Aristotle offers in *Phys* VI, **Conn** is just a starting point. See sections 3.1 and 4.1 below.

3. Aristotle's Accounts of Continuous Connection in Phys. V 3, Metaph. Δ 6 and I 1

3.1. Phys. V 3

The first sentence in *Phys*. VI (T19, see below), featuring **Conn** as quoted above (T2), suggests that *Phys*. VI is continuous with the account of continuous connection in *Phys*. V 3. But I don't think that there is any such continuity. Arguably, *Phys*. V 3 is not about motion at all.

3.1.1. Phys. V 3 describes five kinds of relation – in contact (*haptomena*),[16] between (*metaxu*), successive (*ephexēs*), contiguous (*echomena*), and continuously connected (*sunechē*) – which may obtain between bodies or other kinds of components. The pair of concepts introduced at the beginning of the chapter, together (*hama*) and separate (*chōris*), refer explicitly to place, and so does therefore the subsequent definition of contact (T11) which, in turn, is presupposed in the definition of continuous connection (T14 below). This suggests that the definitions offered in *Phys*. V 3 are primarily meant to apply to bodies and places.[17] I will argue that this is confirmed both by the metaphors and examples in *Phys*. V 3 and by the parallels in the *Metaphysics*.

The definition of "together", "separate", and "in contact" is this.

T11. I say things are together in place (*hama … kata topon*) when they are in one primary place and to be apart when they are in different places. Things are said to be in contact when their extremities are together (*hama*).[18]

Two remarks are in order. *First*. In T11, the concept of primary place is employed to define contact. Conversely, *Phys*. IV 4 employs the concept of

[16] In this list, I am giving the Greek adjectives in neuter plural, to apply to any pair of items, including bodies (*sōmata*). Note that both *metaxu* and *ephexēs* are adverbs.

[17] See Furley (1982) p. 31: "Aristotle's doctrine [*sc*. in *Phys*. V 3] is formulated with reference to physical bodies." Similarly, Waschkies (1977) p. 168 and *passim*.

[18] *Phys*. V 3.226b21-23: **ἅμα** μὲν οὖν λέγω ταῦτ' εἶναι | κατὰ τόπον, ὅσα ἐν ἑνὶ τόπῳ ἐστὶ πρώτῳ, **χωρὶς** δὲ ὅσα | ἐν ἑτέρῳ, **ἅπτεσθαι** δὲ ὧν τὰ ἄκρα ἅμα (tr. *ROT*).

contact to define primary place.[19] *Second*, T11 is incoherent unless the second occurrence of "together" echoes the first.[20] Hence, the "extremities" (*akra*) mentioned in the definition of "in contact" are supposed to be "in a primary place" (*en … topōi … prōtōi*). But the definition at *Phys*. IV 4.212a6 equates the primary place of an entity with "the edge (*peras*) of the surrounding body" and thereby precludes extremities (*eschata*) such as points, lines and surfaces from being in a primary place.[21] I agree with Pfeiffer (2018, pp. 152-3 and 155) that, therefore, T11 does not presuppose the definition offered in *Phys*. IV 4.

Even more conspicuous is the inconsistency between the account of change (*metabolē*) in *Phys*. V 1 and the account of motion (*kinēsis*) in *Phys*. III 1 which, in turn, relies on the account of becoming (*genesis*) in *Phys*. I 7. In *Phys*. III 1, changes in all categories count as movements, whereas only changes in the subordinate categories (quality, quantity, place) are so classified in the second part of *Phys*. V 1. Arguably, the issue is not just classification. Rather, the author of that section in *Phys*. V is unaware of the analysis of unqualified becoming in *Phys*. I 7 where portions of stuff are allowed to substitute substances as subjects. As a consequence, becoming is from just not-being in *Phys*. V 1 – which amounts to the very doctrine the argument in *Phys*. I 7-9 is designed to refute.

That in both cases, the relevant passages in *Phys*. V – ch. 3 and ch. 1 from 224b35 onwards – are earlier than *Phys*. I-IV is quite a safe guess. But it should be added that this does not apply to the whole of *Phys*. V. There are also passages in *Phys*. V which presuppose *Phys*. I-IV – e.g.

- the first part of ch. 1 (up to 224b35) where *Phys*. III 1 seems to be cited (224b10-11),[22] while the classification offered in the second part of the chapter is conspicuously absent, and

[19] *Phys*. IV 4.211a29-34 and 212a5-6a; see Heinemann (2021) pp. 298-300 (note on 211a23-34).
[20] Differently, Alexander (*In Phys*. fr. 254 Rashed, cf. Simplicius, *In Phys*. 870.10-871.15) and Katz (2021) pp. 245 ff.
[21] Aristotle is explicit about points (see *Phys*. IV 1.209a11-13 and 5.212b24-25). That the argument extends to lines and surfaces is hard to deny.
[22] See Ross (1936) p. 8; Wagner (1979) p. 591; Odzuck (2014) p. 26 n. 48.

- the excursus on changes of changes in ch. 2 where *Phys*. I 7 is quoted.[23]

In sum, it is wise to consider the possibility that *Phys*. V is just patchwork and, therefore, to interpret the main sections independently of each other. If chapters 1-2 and 4-6 are, in their respective ways, about motion there is no warrant to conclude from this that ch. 3, too, was written with a view to the analysis of motion. There is, of course, no denying that *Phys*. V as a whole is about motion and so is derivatively ch. 3, as a section inserted into the book.

3.1.2. A crucial passage in *Phys*. V 3 is the definition of betweenness.

T12. (a) That item is between, which the changing thing, changing continuously, naturally reaches before the item to which it naturally changes at the end. ... **(b)** And a thing moves continuously if it leaves no, or just the minimal, gap in the matter (*tou pragmatos*) – not in the time (for, on the one hand, there is no objection to leaving a gap in time [and making a break], but, on the other hand, [the condition that no gap in time is left does not preclude] the highest note sounding immediately after the lowest) but in the matter, [i.e. the dimension] in which the movement takes place.[24]

Ad (a). The definition of betweenness is in terms of linear order (b24: *proteron*, b25: *eschaton*). But linear order is in quite an artificial way imposed on the underlying realm, viz., via itineraries being "natural" (b24: *pephuke*, b25: *kata phusin*) or not.[25] That the relata of betweenness are meant to be 2- or 3-

[23] At *Phys*. V 2.226a17 *hupokeimenē phusis* is a verbatim quotation of *Phys*. I 7.191a8. Throughout the excursus (225b16-226a23), the term *hupokeimenon* is used in the same way as in I 7-9. The special meaning of *hupokeimenon* presupposed in the second part of V 1 ("the state indicated by an affirmative predication": *to anaphase dēloumenon*, 225a6-7; see *Int*. 6.17a25 and my note on 225a3-7 in Heinemann, forthcoming) reappears only in *Phys*. V 5-6 (229a31-32 and b30, but not 230a11). – See the introduction and notes in Heinemann (forthcoming) for a fuller account, and discussion, of the incoherences mentioned.

[24] *Phys*. V 3.226b23-25, 27-31: μεταξὺ δὲ | εἰς ὃ πέφυκε πρότερον ἀφικνεῖσθαι τὸ μεταβάλλον ἢ εἰς ὃ | ἔσχατον μεταβάλλει κατὰ φύσιν συνεχῶς μεταβάλλον, ... [(b27)] συνεχῶς δὲ κινεῖται τὸ μη|θὲν ἢ ὅτι ὀλίγιστον διαλεῖπον τοῦ πράγματος – μὴ τοῦ χρόνου | (οὐδὲν γὰρ κωλύει διαλείποντα, καὶ εὐθὺς δὲ μετὰ τὴν ὑπά|την φθέγξασθαι τὴν νεάτην) ἀλλὰ τοῦ πράγματος ἐν ᾧ | κινεῖται. Concerning the passage in parentheses (*ou gar kōluei* ..., b29-30), I try to follow the proposal offered by Ross (1936) pp. 627-8. – Note that the "highest" string (*hupatē*) is lowest in pitch (LSJ *s.v.*).

[25] Differently, Pfeiffer (2018) p. 148 n. 4: "'between' ... is a notion that is most explicitly linked to the analysis of change"; Mendell (2019, Supplement on § 9: "Place and Continuity of Magnitudes"): "Between (*metaxu*) pertains to continuous change: what is between is that

dimensional regions, e.g., cities, is quite a safe guess. Verona is between Venezia and Milano, because it is "natural" to travel from Venezia to Milano via Verona. But Milano is not between Venezia and Verona, because it is unnatural to travel from Venezia to Verona via (e.g., Bologna and) Milano. Note that this is not just a matter of straight lines (try to travel a straight line from Torino to Grenoble). True, in the context (226b32-34) Aristotle also adumbrates an account of betweenness in terms of straight lines and distances. But he would insist that Lamia is between Athens and Larisa, and that my elbow is between my hand and my shoulder, whether I bend the arm or not. In neither field, consideration of straight lines is to the point.

Ad (b). The change involved in the itinerary account of betweenness is required to be "continuous" (b25: *sunechōs*) – which is said to mean that jumps are confined to a minimum, whereas breaks are explicitly allowed (cf. b28: *mē tou chronou*). For instance, to perform a full scale on a harp counts as a continuous movement, the continuity is only disrupted if a note is omitted (or if the highest note follows the lowest (b29-30). Clearly, the performance satisfies neither **Divi** nor **Conn**. Neither definition of continuity applies; and nothing suggests that the change, which is involved in the definition of betweenness, is meant to instantiate either of them. Rather, "continuously" (b25: *sunechōs*) is common language in T12.[26]

3.1.3. According to Glasner (2020, p. 29), "whereas in *Physics* VI continuity is an attribute of a magnitude, in V.3 it is a binary relation and applies to physical entities as well." This suggests that in V 3, continuity also applies to magnitude according to Glasner. To substantiate, she adds (*ibid*., n. 95) that, in *Phys*. V 3, "Aristotle uses mathematical examples (lines, units) as well as physical examples (houses in a row, rivets, glue)." Rivets (my "nail": *gomphos*, 227a17, see T15 below) and glue are mentioned by Aristotle as ways to establish a continuous connection of bodies (T14, cf. T 17 below). The other examples pertain to succession:

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which a continuous changer arrives at before it arrives at the end of the change." – In my interpretation, change is just auxiliary here: betweenness transfers from change (where the definition is obvious) to the realm at issue via itineraries (similarly, Dehn 1936, pp. 14-5 and 1975, pp. 202-3 and Waschkies 1977, pp. 162-3).

[26] Similarly, Waschkies (1977) pp. 168-9 and Sattler (2020) p. 303 n. 86.

T13. An item is next in succession when (i) it is after the beginning in position, in kind, or by some other criterion, and when (ii) there is nothing of the same genus between it and that to which it is next in succession, e.g. a line or lines if it is a line, unit or units if it is a unit, a house if it is a house.[27]

Examples added in *Phys*. V 3 to this are numbers and calendar dates on the one hand (227a5-6) and points on the other (a27-32); numbers reappear at a20 and a32, units (a2-3) at a27-32. All of this pertains to succession, but in the latter passage, contact is also mentioned. The passage is probably meant to bring out a difference between units (as employed in the definition of numbers) and points.[28] If nothing is between them, units are in succession, but points are in touch. If points are separate, a line is between, but separate units may be successive and, in this case, have nothing between them. If so, the message is a negative one: The definition of succession is not primarily meant to apply to points.

In sum, the mathematical examples in *Phys*. V 3 pertain to succession only. None of them pertains to continuous connection. Glasner's remark, as quoted above, is misleading. She should have said that, as a rule, Aristotle's examples in *Phys*. V 3 are physical, but in one of the cases, succession, he uses mathematical examples as well.

3.1.4. The definition of continuous connection offered in the sequel is this.

T14. An item is contiguous when it is next in succession and in contact. Continuity (*to suneches*) is a special case of contiguity: I say there is continuous connection when the limits of each, by which they are in contact, have become one and the same and are, as the word implies, kept together: which is impossible if the extremities are two.[29]

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[27] *Phys*. V 3.226b34-227a3: **ἐφεξῆς** δὲ οὗ μετὰ τὴν ἀρχὴν | ὄντος ἢ θέσει ἢ εἴδει ἢ ἄλλῳ τινὶ οὕτως ἀφορισθέντος | μηδὲν μεταξὺ ἐστι τῶν ἐν ταὐτῷ γένει καὶ οὗ ἐφεξῆς ἐστιν | (λέγω δ' οἷον γραμμὴ γραμμῆς ἢ γραμμαί, ἢ μονάδος μο|νὰς ἢ μονάδες, ἢ οἰκίας οἰκία· ...) (tr. *ROT*, modified)

[28] See Waschkies (1977) pp. 221 ff. (particularly pp. 231-2).

[29] *Phys*. V 3.227a6-7, 10-13: **ἐχόμενον** δὲ ὃ ἂν ἐφεξῆς | ὂν ἅπτηται. [(a10)] τὸ δὲ **συνεχὲς** ἔστι μὲν ὅπερ ἐχόμενόν τι, | λέγω δ' εἶναι συνεχὲς ὅταν ταὐτὸ γένηται καὶ ἓν τὸ ἑκατέρου | πέρας οἷς ἅπτονται, καὶ ὥσπερ σημαίνει τοὔνομα, συνέχη|ται. τοῦτο δ' οὐχ οἷόν τε δυοῖν ὄντοιν εἶναι τοῖν ἐσχάτοιν (tr. *ROT*, modified).

The crucial concepts involved in this are becoming and activity: limits *become* one and, thereby, acquire a *causal* role in the connection. In the sequel, Aristotle leaves no doubt that this is not just a matter of metaphor, as it arguably is in T7-T10. – An addition to T14 distinguishes natural from artificial unity and explains what they have in common.

T15. This definition makes it plain that continuity belongs to things from which a unity is naturally created (*pephuke gignesthai*) at their junction. And in whatever way that which keeps them together becomes (*gignetai*) one, so too will the whole be one, e.g., by nail or glue or contact (i.e., fit and/or clamp) or ongrowth.[30]

The distinction (which *Metaph.* Δ 6 brings out more clearly, see T17 below) is again in terms of becoming. Examples of artificial unity are described by the causal factor which accounts for the unity and which in all three cases may be assumed to reside at the junction of the parts:[31] evidently so in the case of the glue, whereas both nail and clamp need fitting surfaces to fix the parts in their relative positions. By contrast, "ongrowth" (*prosphuomai / prosphusis*) is a technical term adopted by Aristotle from medicine.[32] Aristotelian examples include: the embryo, cord, and egg, in the uterus;[33] inner and outside parts of the animal body;[34] univalves on a rock;[35] the cohesion of materials.[36] More examples may be adduced from the use of *prosphuēs* and

[30] *Phys*. V 3.227a13-17: τούτου | δὲ διωρισμένου φανερὸν ὅτι ἐν τούτοις ἐστὶ τὸ συνεχές, ἐξ | ὧν ἕν τι πέφυκε γίγνεσθαι κατὰ τὴν σύναψιν. καὶ ὥς ποτε | γίγνεται τὸ συνέχον ἕν, οὕτω καὶ τὸ ὅλον ἔσται ἕν, οἷον ἢ | γόμφῳ ἢ κόλλῃ ἢ ἁφῇ ἢ προσφύσει (tr. *ROT*, modified). – I am taking *kata* (a15) in the local sense, but a causal sense cannot be ruled out (on which see footnote 31 below). Concerning "by ... contact" (*haphē*$_i$, a17) see Simplicius, *In Phys.* 878.20-21: "by fitting together like a ship" (tr. Urmson).

[31] The *ROT* takes *kata* (227a15) in the causal sense. If this is correct, the causal claim is explicit in T15. Otherwise, inspection of the examples must do.

[32] [Hippocrates], *Artic*. 41 and 45; *Epid*. VII 1, 57 and 92; *Morb*. IV 17 (48 L.) and *passim*; cf. *prospephuka* at *Epid*. II 4, 1 and *passim*. Diogenes of Apollonia, DK 64 B 6 (VS II, 64.1).

[33] *Metaph.* Δ 4.1014b22; cf. *GA* II 7.745b24 and b33-33a; *GA* III 3.754b12 ff. and *passim*.

[34] *HA* I 17.496b29; *HA* III 9.517a21; *Inc*. ch. 16.

[35] *PA* IV 4.679b23; cf. *GA* I .715a17.

[36] *Meteor*. IV 9.377a3.

prosphus in Homer: a bench is "attached" to a chair, Odysseus is "attached" like a bat to a tree, and Hekabe wishes to devour Achilles' liver, "attached to it."[37]

In the sequel, the "genetic" account (*kata tēn genesin*) equates continuous connection with "natural unity" (*sumphusis*) resulting from "growing together" (*sumphuomai*):

T16. So natural union is last in coming to be; for the extremities must necessarily come into contact if they are to grow together; but things that are in contact are not all grown together, while where there is no contact clearly there is no natural union either.[38]

Examples of *sumphusis* include liquids (see T6 above), but *sumphuomai* /*sumphusis* is mainly a more or less technical term with applications in (comparative) anatomy,[39] embryology,[40] and medicine.[41] There is also a prehistory of the term in Empedocles, with connotations from botany,[42] to which, however, Aristotle does not seem to allude.

In *Phys*. V 3, there is nothing to suggest that the account of continuous connection is meant to apply to linear continua such as path, motion, and time. The transfer to the latter realm is confined to a section of *Phys*. V 4 (228a20-b11, see T9 and T10 above), and to the beginning of *Phys*. VI (see T19 below). In both cases, the shorthand indicating the account in V 3 is **Conn**.[43]

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[37] My "attached" corresponds to *prosphue'* = *prosphuea* at *Od*. XIX 58, *prosphus* at *Od*. XII 433, and *prosphusa* at *Il*. XXIV 213. – Note that *phu-* connotes firm connection rather growth here.

[38] *Phys*. V 3.227a23-27: ὥστε ἡ σύμφυ|σις ὑστάτη κατὰ τὴν γένεσιν· ἀνάγκη γὰρ ἅψασθαι εἰ | συμφύσεται τὰ ἄκρα, τὰ δὲ ἁπτόμενα οὐ πάντα συμπέ|φυκεν· ἐν οἷς δὲ μὴ ἔστιν ἁφή, δῆλον ὅτι οὐκ ἔστιν οὐδὲ | σύμφυσις ἐν τούτοις (tr. *ROT*, modified).

[39] Paired limbs connected at the spine: *Inc*. 6.706b26; similarly, [*Hippocrates*], *Art*. 34, IV 154.12 L. etc.; *Fract*. 37, III 542.4 L. In cycads, mouth and tongue are grown together to form a sucking tube (*PA* IV 5.682a20). Similarly, beaks may be imagined as being formed from teeth (*PA* II 16.659b24). See Kullmann (2007) p. 660 and p. 479, respectively.

[40] See, e.g., *GA* IV 4.769b33, 773a3, etc. on the formation of monstrosities.

[41] See, e.g., *HA* III 515b19 where *ou sumphuetai* indicates that a cut does not heal. Similarly, [*Hippocrates*], *Fract*. 24, III 496.4-5 L. and *Art*. 14, IV 120.1 L.

[42] DK 31 B 26.7/9: *sumphuomai* / *diaphuomai*. Similarly, B 17.7/10 etc.; B 95. Clearly, the description of the elements as "roots" (*rhizōmata*, B 6.1) connotes herbally.

[43] In T10, "has been established" (*keitai*, 228a29), may refer to T14, but the final clause in T9 (... *hosōn hen ta eschata*, 228a23-24: "... of which the extremities are one") would also do.

3.2. Metaph. Δ 6 and I 1

Again, continuity is clearly conceived as continuous connection. The relevant passage in *Metaph.* Δ 6 is this.

T17. (1) Of things called one in their own right some are so called because they are continuous, e.g. a bundle by a band, and pieces of wood by glue; and a line, even if it is bent, is called one if it is continuous, as each part [of the body] is, e.g. a leg or an arm. Among these, what is the continuous by nature is more one than what is continuous by art. **(2)** A thing is called continuous whose movement in its own right is one and cannot be otherwise; and the movement is one when it is indivisible, i.e., temporally indivisible. And those things are continuous in their own right which are one not [sc. merely] by contact.[44]

To the account in *Phys*. V 3, four claims are added. (i) Continuity is a special case of oneness; (ii) kinematic unity is the mark of continuity; (iii) the bundle is an example; (iv) continuity admits of degrees of oneness: what is continuous by nature is more one (*mallon hen*, a4) than what is continuous by art. The crucial addition, that kinematic unity is the mark of continuity, is evidently confirmed by the examples adduced in T15: nail, glue, fit (and/or clamp), and ongrowth. It is quite a safe guess that the accounts of continuity in *Phys*. V 3 and in *Metaph.* Δ 6 complement each other.

In *Metaph.* I 1, still another amendment is (v) the distinction between kinematic unity (i.e., continuity in the sense of T17) and unity "in account" (*ton logon*). In the relevant passage (1052a16-b1), four meanings of 'one' are distinguished: "the naturally continuous, the whole, the individual, and the universal" (a34-36), which reduce to two cases as follows.

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[44] *Metaph.* Δ 6.1015b36-1016a7: τῶν δὲ καθ' ἑαυτὰ ἓν λεγομένων τὰ μὲν λέγεται τῷ |(a1) συνεχῆ εἶναι, οἷον φάκελος δεσμῷ καὶ ξύλα κόλλῃ· | καὶ γραμμή, κἂν κεκαμμένη ᾖ, συνεχὴς δέ, μία λέγεται, | ὥσπερ καὶ τῶν μερῶν ἕκαστον, οἷον σκέλος καὶ βραχίων. | αὐτῶν δὲ τούτων μᾶλλον ἓν τὰ φύσει συνεχῆ ἢ τέχνῃ. | (a5) συνεχὲς δὲ λέγεται οὗ κίνησις μία καθ' αὑτὸ καὶ μὴ οἷόν | τε ἄλλως· μία δ' οὗ ἀδιαίρετος, ἀδιαίρετος δὲ κατὰ χρόνον. | καθ' αὑτὰ δὲ συνεχῆ ὅσα μὴ ἁφῇ ἕν· (tr. adopting features from *ROT* and Kirwan). "Temporally indivisible" – that is, parts move all at once, not one after another ("i.e.": *de*, a6). Note that in T17, section (1) is about oneness; only section (2) is explicitly about continuity.

T18. And all these are one because in some cases the movement, in others the thought or the account, is indivisible.[45]

Whether T18 denies that unity in account may also feature in **Conn**, be it as a ground of natural unity (*phusei*, *ibid.*, a20) or as an addition to it, is hard to say. On the one hand, for movements to be continuously connected, sameness in account (which secures that the composite whole be one in account) is a requirement according to *Phys*. V 4 and *Phys*. VIII 8.[46] Yet, on the other hand, both *Phys*. V 3 (T14-T16) and *Metaph.* Δ 6 (T17) suggest that the limits of heterogeneous bodies may be one, and the bodies be continuously connected by this.[47] This is just the case with the examples mentioned in T15 and T17. In particular, heterogeneous bodies which share one common limit meet the requirement which in the *Metaphysics* (T17, T18) is the mark of continuity: if the limits are together, but two, the bodies are movable against each other, and the limit of one of them may serve as the place of the other (see T4; note that a place can be left, see, e.g., *Phys*. IV 4.211a2-3); but if the bodies share one common limit, they also share one common place and, hence, neither of them moves without the other moving simultaneously.

Both *Phys*. V 3 and the parallels in *Metaph.* Δ 6 and I 1 attribute continuity to composite wholes which, as a rule, fail to be one in account. Hence, it is quite a safe guess that the cases distinguished in T18 are meant to be disjoint. – It goes without saying that continuity of motion is not at issue in *Metaph.* Δ 6 and I 1. Kinematic unity is the mark of continuity here. But according to Aristotle (*Phys*. V 2.225b13-226a23), movements don't move in any conceivable way.[48] Hence, kinematic unity of movements is a contradiction in terms.

It may be argued that, by contrast, **Divi** presupposes unity (so as to have something to divide), and that unity in account is a strong candidate. The argument would refer to the account of motion in *Phys*. III 1-3 as follows.

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[45] *Metaph*. I 1.1052a36-b1: πάντα δὲ ταῦτα ἓν τῷ ἀδιαίρετον εἶναι τῶν μὲν | τὴν κίνησιν τῶν δὲ τὴν νόησιν ἢ τὸν λόγον (tr. *ROT*, modified). – Note that *logos* (b1) corresponds to *eidos*, *ibid*., a23.

[46] *Phys*. V 4.228b2: *tōi eidei* (see T10 above); *Phys*. VIII 8.262a2: *kat' eidos* = *tōi eidei* (a5) = *tōi logōi* (a21), see footnote 15 above.

[47] See also the remark at *Metaph.* Δ 4.1014b26 that diversity in quality (*kata to poion*) is compatible with having grown together (*sumpephukenai*, *ibid*., b25).

[48] Except per accidens (*Phys*. V 2.226a19-23), which no option here.

Aristotle's definition of motion – "fulfilment (*entelecheia*) of the thing which is potentially [sc. in the final state] qua such [i.e., qua being potentially in the final state]" (ch. 1.201a10-11) – refers to a final state which, in general, is specified externally as follows. Next to the thing moved (*to kinoumenon*), there is also a mover (*to kinoun*) which "will introduce a form" (*eidos ti oisetai*) which, in turn "will be the principle and cause of the movement" (ch. 2.202a9-11). Insofar as the movement derives its unity from that form, it is one "by form" (*eidei*) and hence "in account" (*ton logon*).

4. Continuity in Phys. VI 1-2

In *Phys*. VI 1, **Conn** is the just a starting point, to be dismissed as a definition of continuity after **Divi** is derived in the middle of the chapter (231b16, see T25 below). In the rest of the book, Aristotle's account of continuity is in terms of **Divi** rather than **Conn**.

4.1

The first part of *Phys*. VI 1 (up to 231b18) is quite a mess. Leaving a fuller discussion to another occasion,[49] I will confine myself to a proposal and some sketchy remarks. – The opening sentence refers **Conn** back to *Phys*. V 3.

T19 (>T2). If continuous[ly connected], in contact, and next in succession are these, as defined earlier,
- continuous[ly connected]: items of which the extremities are one,
- in contact: items of which [the extremities] are together,
- next in succession: items with nothing of the same genus between,

something continuous cannot be composed of indivisible items, e.g., a line of points, if indeed the line is [something] continuous, and the point is [something] indivisible.[50]

The statement in T19 of the theorem that "a continuum (*ti suneches*) cannot be composed of indivisibles" (a24) leaves it open (a) what a continuum is, and (b) what it is to be composed of something.

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[49] See my introduction and notes in Heinemann (forthcoming).

[50] *Phys*. VI 1.231a21-26: Εἰ δ' ἐστὶ συνεχὲς καὶ ἁπτόμενον καὶ ἐφεξῆς, ὡς | διώρισται πρότερον, συνεχῆ μὲν ὧν τὰ ἔσχατα ἕν, ἁπτό|μενα δ' ὧν ἅμα, ἐφεξῆς δ' ὧν μηδὲν μεταξὺ συγγενές, | ἀδύνατον ἐξ ἀδιαιρέτων εἶναί τι συνεχές, οἷον γραμμὴν ἐκ | στιγμῶν, εἴπερ ἡ γραμμὴ μὲν συνεχές, ἡ στιγμὴ δὲ ἀδιαί|ρετον.

Ad (a). The definition offered at the beginning (a22) does not apply since in both the theorem (a24) and the subsequent example, "continuous" (*suneches*) is a one-place predicate whereas the definition is of a two-place predicate (viz. **Conn**). Aristotle nowhere explains the former in terms of a latter.[51] The example is all he offers: lines are continua, and points are indivisibles. In order to make sense of the sequel (231a26-b18), it is wise to assume Aristotle is talking just about lines and points (or periods and instants, b6 ff.), but not about continua in general.

Ad (b). I propose that a parallel passage in *GC* I 2 may be adduced which requires that composition be of, and division be into, contiguous parts:

T20. ... for point is not contiguous with point. But this [i.e., into or out of contiguous items, respectively] is division or composition.[52]

As a consequence, both composition and division are at a point which is the common limit (*eschaton*, 232a22) of the parts (or at a junction where the limits coincide, if coincidence of points is allowed, cf. T22). Thus, the initial claim (T19) boils down to the observation that a line cannot be composed of points for one of two reasons: either because points are not contiguous, see

T21. Neither is it the case that the extremities of the points are one, since the indivisible fails to have both an extremity and a part which is distinct [from the extremity]. Nor is it

[51] Waschkies (1977, p. 7) claims that "am Anfang von *Phys.* VI 1", Aristotle "charakterisiert ... die Kontinua als diejenigen Gesamtheiten, bei denen die Enden benachbart liegender Teilstücke in eins zusammenfallen." According to Bostock (2006, pp. 161-2), "the (unstated) definition of what a continuum is", presupposed by the argument at 231a24-b18 is this: "a continuum is anything which (i) can be divided into two parts, and (ii) is such that any two parts into which it is divided must share a limit" – i.e. are continuously connected (GH). Bostock adds that the definition fails to exclude such pathological examples as a half-open interval being continuously connected with its missing edge – which, on the one hand, would beg the question but, on the other hand, is required to save the definition from emptiness (*ibid*., pp. 162-3). By contrast, I don't see any definition of a relevant one-place predicate being presupposed here.

[52] *GC* I 2.317a11-12: ... οὐ γὰρ ἐστιν ἐχόμενον σημεῖον σημείου ἢ | στιγμὴ στιγμῆς. Τοῦτο δ' ἐστὶ διαίρεσις ἢ σύνθεσις. – Following Sedley (2004, p. 78 n. 27), I take *semeion* and *stigmē* to be synonyms: *ē stigma stigmēs* is just a repetition and is skipped in my translation.

the case that the extremities are together, since the partless fails to have an extremity at all; for the extremity and the thing of which it is the extremity are distinct.[53]

or, if points are allowed to be contiguous, because contiguous points are together and therefore fail to make up a line in which points are apart, see

T22. Things are in contact either whole with whole, or part with part, or whole with part. Since the indivisible is partless, it must be in contact whole with whole. But what is in contact whole with whole, does not make up a continuum. For a continuum has parts which are distinct from each other and is correspondingly divided into distinct parts which are spaced apart.[54]

As an aside, the theorem stated in T19, that "something continuous cannot be composed of indivisible items", may be also understood in a more general sense: that indivisibles are (i) limits, but (ii) not parts. While (i) is argued for in *Phys*. VI 3, a proof of (ii) is offered in the second half of VI 1 (see below section 4.2).

In the sequel (T23-T25), the leading question pertains no longer to the composition of lines out of points, but to the way in which the points which occur in a line (or the instants which occur in a period of time) are arranged. Atomism considers two kinds of arrangement: succession (i.e., separation by void) and contact. For points (and equivalently, instants), contact was ruled out by T21 and T22. Concerning succession, points (and instants) are different from atoms in that between Democritean atoms, there is nothing,

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[53] *Phys*. VI 1.231a26-29: οὔτε γὰρ ἓν τὰ ἔσχατα τῶν στιγμῶν (οὐ γάρ ἐστι τὸ | μὲν ἔσχατον τὸ δ' ἄλλο τι μόριον τοῦ ἀδιαιρέτου), οὔθ' ἅμα | τὰ ἔσχατα (οὐ γὰρ ἐστιν ἔσχατον τοῦ ἀμεροῦς οὐδέν· ἕτερον | γὰρ τὸ ἔσχατον καὶ οὗ ἔσχατον). Remark: Democritean atoms are extended and therefore mathematically divisible. Hence, extremities may count as parts in the mathematical sense, whereas the atom is still indivisible in the physical sense. But this distinction does not transfer from physical atoms to points. That's why Aristotle oddly presupposes that (i) extremities are parts (cf. a27: *morion*) and that, equivalently, (ii) something which is indivisible (*to ameres*, a28) admits of no distinction of an extremity from the thing of which it is an extremity. As an alternative, he will assume in T22, that (iii) a point and its extremity are the same.

[54] *Phys*. VI 1.231b2-6: ἅπτεται δ' ἅπαν ἢ ὅλον ὅλου ἢ μέρος μέρους ἢ ὅλου μέρος. | ἐπεὶ δ' ἀμερὲς τὸ ἀδιαίρετον, ἀνάγκη ὅλον ὅλου ἅπτεσθαι. | ὅλον δ' ὅλου ἁπτόμενον οὐκ ἔσται συνεχές. τὸ γὰρ συνεχὲς | ἔχει τὸ μὲν ἄλλο τὸ δ' ἄλλο μέρος, καὶ διαιρεῖται εἰς | οὕτως ἕτερα καὶ τόπῳ κεχωρισμένα.

whereas in the case of points, "what is between is always a line" (and a period of time between instants) according to Aristotle, see

T23. But neither is point successive to point or now to now in such a way that length or time are composed of these. For things are in succession which have nothing of the same genus is between them; but in the case of points, what is between is always a line, and in the case of nows, [a period of] time.[55]

On the one hand, points are in succession, iff no points are between. As a consequence, the line which separates a point from its successor must be indivisible. For T20 requires that division be at a point, and that at every point there can be a division. Hence, on the other hand, a line in which the points are in succession must be composed of the indivisible lines between those points, see

T24. Further [if length and time are composed of successive points or nows, respectively (b6-8)], both would be divided into indivisible parts [i.e. (?), indivisible lines between successive points (b9), or indivisible periods between successive instants (b10), respectively], assuming that each of the two [i.e. length and time] is divided into the items of which it is composed [i.e. (?), the lines or periods between the successive points (b9) or instants (b10), respectively]. But none of the [two (?)] continua were divisible into indivisibles.[56]

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[55] *Phys*. VI 1.231b6-10: ἀλλὰ μὴν οὐδὲ ἐφεξῆς | ἔσται στιγμὴ στιγμῇ ἢ τὸ νῦν τῷ νῦν, ὥστ' ἐκ τούτων εἶναι τὸ | μῆκος ἢ τὸν χρόνον· ἐφεξῆς μὲν γάρ ἐστιν ὧν μηθὲν ἐστι με|ταξὺ συγγενές, στιγμῶν δ' αἰεὶ τὸ μεταξὺ γραμμὴ καὶ τῶν | νῦν χρόνος (text: Ross deletes τό before μεταξύ, b9). Remark. Aristotle may presuppose here that points and lines (and instants and periods) are same in *genos*, the doctrine that in geometry, dimensions are *genē* (*Top*. VI 6.143b11 ff.; *Cael*. I 1.268b1; *Metaph*. Δ 28.1024b1) being no to the point here. Otherwise, the relevant argument will only follow in the sequel (T24, T25). – See also remark (b) on T25 below.

[56] *Phys*. VI 1.231b10-12: ἔτι διαιροῖτ' ἂν εἰς ἀδιαίρετα, εἴπερ ἐξ ὧν ἐστιν | ἑκάτερον, εἰς ταῦτα διαιρεῖται· ἀλλ' οὐθὲν ἦν τῶν συνεχῶν | εἰς ἀμερῆ διαιρετόν. Remarks: (a) My additions are meant to make sense of the argument. The reference to b6-8 is in Simplicius and Ross. The reference to b9-10 is a tentative proposal of mine. (b) Is "none of the continua ..." (b11-12) a universal statement, as "something continuous ..." (*it suneches*, a24, see T19 above) and "all continua ..." (b16) clearly are? At. b11-12, "none of the two" might make a better sense. But Ar. writes *outhen* rather than *oudeteron*. (c) Where is the argument for the denial of "divisible into indivisibles" (b11-12)? The past tense suggests: earlier. But the argument at a26-b6 is about composition, not division. Note that a relevant argument is offered at b16-18, which draws on a26-b6. Accordingly, I suppose that, again, (T20) applies.

But since the line, which separates a point from its predecessor, and the line, which separates the same a point from its successor, are contiguous, the argument in T21 applies: neither line can be indivisible. In sum, it is thereby demonstrated that the points in a line (and equivalently, the instants in a period of time) are dense rather than successive, and **Divi** is satisfied), see

T25. And there can be no other genus between the points and the news. For, otherwise, it is clearly either indivisible or divisible, and if divisible, either into indivisibles or into again and again divisibles. But this [i.e. (?), the line or period between successive points (b9) or instants (b10), respectively] is a continuum. And it is also evident that every continuum is divisible into again and again divisibles – for, if into indivisibles, indivisible is in contact with indivisible, since the extremity of continuous[lee connected] items is one and in contact.[57]

While **Conn** is a principle of composition, **Divi** is a feature which occurs in *analysis*. T24 indicates a stepwise correspondence between *synthesis* and *analysis* (b10-11). But **Divi** entails that *analysis* is never completed and therefore provides no starting point for *synthesis*. That's why *synthesis* via **Conn** fails to fully account for the structure of continua and, in particular, provides no definition of "a continuum" (*ti suneches*, 232a24, T19), see above ad (a).[58] In the sequel, Aristotle's account of continuity is in terms of **Divi** (*analysis*) rather than **Conn** (*synthesis*).

I have offered quite a benevolent interpretation of *Phys*. VI 1.231a21-b18 (i.e., T19-T25). If, as I believe, my proposal is consistent with the text, Aristotle's argument in the initial section of *Phys*. VI is still hard to follow but not hopelessly confused. But the real stuff is yet to come. I will confine myself to the isomorphism exhibited in the second part of ch. 1 (231b18 ff.)

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[57] *Phys*. VI 1.231b12-18: ἄλλο δὲ γένος οὐχ οἷόν τ' εἶναι μεταξὺ | τῶν στιγμῶν καὶ τῶν νῦν οὐθέν. εἰ γὰρ ἔσται, δῆλον ὡς ἤτοι | ἀδιαίρετον ἔσται ἢ διαιρετόν, καὶ εἰ διαιρετόν, ἢ εἰς ἀδιαί|ρετα ἢ εἰς ἀεὶ διαιρετά· τοῦτο δὲ συνεχές. φανερὸν δὲ καὶ | ὅτι πᾶν συνεχὲς διαιρετὸν εἰς αἰεὶ διαιρετά· εἰ γὰρ εἰς ἀδι|αίρετα, ἔσται ἀδιαίρετον ἀδιαιρέτου ἁπτόμενον· ἓν γὰρ τὸ | ἔσχατον καὶ ἅπτεται τῶν συνεχῶν. Remarks: (a) *de* ("and", b12) – indicates an additional argument. (b) "another genus" (b12): i.e., a line in which no points, or period of time in which no instants, occur (assuming that lines and points are different in genus, and so are periods and instants). Aristotle seems to assume that lines are divided by points, and periods by instants – which is also suggested by (T20). (c) Note that "divisible into" (b16) = composed of (thus securing that T21 and T22 apply).

[58] According to Sattler (2020) p. 296, definition by **Conn** is therefore nominal (and real only by **Divi**).

and to the expansion of it which informs the argument in the first part of ch. 2 (up to 233a12).

The introduction of the isomorphism at 231b18 (see below T26) amounts to a new start. As *Phys*. V is arguably patchwork (see above 3.1.1), so is the whole of *Phys*. V-VI. The **Conn**+sumphusis account of continuity in V 3 and the **Divi**+isomorphism account in VI 1-2 pertain to distinct classes of phenomena and are, therefore, essentially disconnected.

4.2

The primary topic in *Phys*. VI (from 231b18 on) is motion. – The initial phrase in

T26. It is in corresponding ways (*tou autou logou*) that path, time, and movement [are] composed of indivisibles, and are divided into indivisibles, or none[59]

indicates that the same *logos* applies to the composition / division of a "magnitude" (*megethos*, b19 – viz., the path of a movement), of the movement, and of the time the movement takes. I disagree with the prevalent rendering of *logos* by "argument" here: *logos* is the proportion or regularity which obtains in the composition / division. The claim that the *logos* is the same for path, movement, and time amounts to claiming that motion establishes an isomorphism between the three.[60] Aristotle's proof of T26 involves an obvious transfer of structure from path to movement and back (231a21-22, 26-28) and from path to time and back (232a18-22). The description of the transfer involves indivisibles which, however, are not essential to the isomorphism as such. With divisible parts, the construction of the isomorphism

[59] *Phys*. VI 1.231b18-20: τοῦ δ' αὐτοῦ λόγου | μέγεθος καὶ χρόνον καὶ κίνησιν ἐξ ἀδιαιρέτων συγκεῖσθαι, | καὶ διαιρεῖσθαι εἰς ἀδιαίρετα, ἢ μηθέν.

[60] Similarly, Miller (1982) pp. 102 ff., Newstead (2001) p. 117. But I disagree with Miller in some points. (i) His suggestion (*ibid.*, p. 103) that the isomorphism theorem at 231b18-20 presupposes indefinite divisibility, as stated at 231b16, is misleading. (ii) Miller (pp. 106-9) conflates the refutation of indivisibility for path, movement, and time (231b28-232a17) with the refutation of indivisibility for moving bodies in chap. 10.240b8-241a26. (iii) Miller (pp. 104-6) conflates the part-by-part isomorphism established in ch. 1.231b18-28 and 232a18-22 with the limit-by-limit isomorphism assumed in ch. 2.232a31-b5 (and *passim*) which – in my interpretation – is only secured by a tacit application of the continuity principle (see section 4.3 below).

would be just the same. The essential assumption is that a path is composed of, and divided into, paths (T3),[61] from which it follows that so are motion and time.[62]

The correspondence thus established is between the parts into which path, movement, and time are divided. Differently from both the first half of the chapter and the chapters to follow, points dividing a line (etc.) play no role here. Parts are just parts; the mereological approach is only supplemented by a linear ordering of the parts; hence the movement which establishes the isomorphism must be straightforward, that is, without turns, loops, jumps, and breaks.

It is sometimes assumed that uniformity of motion, so as to transfer metric properties, is another requirement. But metric properties have no role to play here – that is, in most of *Phys*. VI. The "traditional account" (cf. 233a13: *ek tōn eiōthotōn logōn*), which employs uniform motion and the so-called Archimedean property and thus presupposes a time metric, prevails only in the second part of chap. 2 (233a13 ff.) and in chap. 7.[63] Arguably, Aristotle's innovative (in modern terms: mereotopological) account is motivated by the notorious circularity in the definition of uniformity: motion is uniform iff$_{Df}$ equal distances are travelled in equal times; and times are equal iff$_{Df}$ the distances travelled by uniform motion are equal. The circularity will be resolved by Aristotle's account in *Phys*. VIII of the primary movement, which is uniform since its drive is unchanging; in *De caelo*, Aristotle adds that another requirement, homogeneity of the path, is in the case of the

[61] Aristotle's notation at 231a22-28 suggest a division into just three parts. But nothing in his argument presupposes that the division is into even a finite number of parts. See my note on 231b20-25 in Heinemann (forthcoming).

[62] Only at *Phys*. IV 11.219a16-19, the transfer of order (*akolouthein*, a19) is explicitly mentioned and described as an isomorphism (*analogon*, a18).

[63] In both sections mentioned, VI 2.233a13-b32 and VI 7, infinity is at issue. The mereotopological approach which prevails in the rest of *Phys*. VI does not distinguish "unlimited" from "open" – and rightly so since, for instance, the part of a line which is between *A* and *B* satisfies Aristotle's definition of "unlimited" (*apeiron*, i.e. *hou aei ti exō esti*, *Phys*. III 6.207a1: "part of which is always outside"). Strictly speaking, the distinction is unnecessary for the theorems to be proved in VI 2 (2nd part) and VI 7; see, in particular, the corrected proofs in VI 10. But the lack of distinction between "unlimited" and "open" may be confusing. Thus, the "traditional" way of argument appears as a didactic device – which, by the way, Aristotle fails in VI 7 to master (see, e.g., Hasper 2021, p. 57).

celestial motions also met.[64] Aristotle's final account of uniform motion is devoid of circularity, but unavailable in *Phys*. VI.

Inserted into the proof of T26 is an argument which establishes that neither path, nor movement, nor time are composed of indivisible parts (231b29-232a17). The argument starts with the assumption that every movement involves two successive events: process and arrival.[65] Hence, the time an indivisible movement takes is divided, and so is its path and therefore, the movement which was assumed to be indivisible (231b28-232a11). – Two remarks are in order. (i) The argument described amounts to another proof that instantaneous motion is a contradiction in terms. (ii) On closer inspection, the argument requires that indivisible parts be densely ordered. It fails if, e.g., every indivisible part of the path has an immediate successor. If *A'* is the immediate successor of *A*, arrival at *A* may coincide with the process of moving towards *A'*. Think of climbing stairs: to be on the *n*th stair is to move to the (*n*+1)th stair.[66]

4.3

In the sequel, all division of path, motion, and time are by extremities of the parts, as **Conn** requires. Thus, **Divi** takes the form of a claim about points, instants, and intermediate states obtaining at instants. It has been rarely observed that the proof in **Divi** in *Phys*. VI 2 employs a version of the continuity principle which is explicitly stated in *Phys*. VII 4 (T27 below), but only tacitly presupposed in VI 2. Its application in the proof of a preliminary

[64] *Phys*. VIII 10.267b2-6; cf. 6.260a17-19; *Cael*. II 6.288a17-27.

[65] *Phys*. VI 1.231b28-232a1: "Something which moves from one place to another cannot simultaneously be travelling and have completed travelling to the place (*hou*) it travelled when it was travelling. For instance, if something [sic!] walks to Thebes, it cannot simultaneously be walking to Thebes and have completed walking to Thebes. Hence, ..." (εἰ | δὴ ἀνάγκη τὸ κινούμενον ποθέν ποι μὴ ἅμα κινεῖσθαι καὶ | κεκινῆσθαι οὗ ἐκινεῖτο ὅτε ἐκινεῖτο (οἷον εἰ Θήβαζέ τι βα|δίζει, ἀδύνατον ἅμα βαδίζειν Θήβαζε καὶ βεβαδικέναι | Θήβαζε), ...) Remark. If *Z* is the moving thing and *A* is a place on its path, my "process" is the event of *Z*'s moving towards *A*, and "arrival" is the event of *Z*'s having arrived at *A*. In the sequel, Aristotle emphasizes that *Z*, while moving (*hote diē͵ei*, 232a3), was neither at *A* (*oute dielēluthei*, *ibid.*) nor at a place from which it started to move towards *A* (*outer ēremēi*, *ibid.*). – Note that the moving thing is treated as unextended here (and throughout *Phys*. VI.1-3).

[66] See my note on 232a2-4 in Heinemann (forthcoming).

lemma at 232a31-b5, and subsequently in the conversion procedure described at 232b27-233a10, is as follows.

Two runners, *A* faster, *B* slower. That is, Aristotle explains, *A* arrives earlier than *B*.[67] Both *A* and *B* start simultaneously at the point *C* into the same direction; the movement of both is straightforward. When *A* arrives at the point *D*, *B* is not yet at *D*, but will be late (*apoleipsei*, 232a30-31). The crucial step, then, is this.[68] If *FG* is the time it takes for *A* to travel from *C* to *D* (232b1) and, hence, *G* is the instant at which *A* arrives at *D*, Aristotle assumes that there is a point *E*, such that *G* is also the instant at which *B* is at *E* (232a31).[69]

Similarly, in the sequel (note that the period *FG* is defined differently here):

If *FG* is the time it takes for *B* (the slower mover) to travel from *C* to *D* and, hence, *G* is the instant at which *B* arrives at *D* (232b28-29), there is an instant *H* earlier than *G* such that *FH* is the time it takes for *A* to travel from *C* to *D* (232b31). Again, Aristotle assumes that there is a point *K*, such that *H* is also the instant at which *B* is at *K* (232b32-233a1).

The existence of instants *G* and *H* is secured by the assumption that the movements are straightforward and, therefore, for every potential place on its path there is an instant at which it is taken in passing. By contrast, the existence of points *E* and *K* (which again represent places) is a matter of continuity.[70] The relevant argument is indifferent to the way in which the instant *G* (or *H*) is determined. What matters is this (similarly for *H* and *K*).

There are points to which *B* gets earlier than *G*, and points to which *B* gets later than *G*. Since the path is linearly ordered,[71] and the movement is

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[67] *Phys*. VI 2.232a28-29: "Faster is what changes first." (θᾶττόν ἐστιν τὸ πρότερον μεταβάλλον.)

[68] *Phys*. VI 2.232a32-33: "In the time [viz., *FG*] it has taken for *A* to get to *D*, let *B*, which is faster, get to *E*." (ἐν ᾧ γὰρ τὸ Α γεγένηται | πρὸς τῷ Δ (i.e., ἐν ... τῷ ΖΗ χρόνῳ, b1), τὸ Β ἔστω πρὸς τῷ Ε τὸ βραδύτερον ὄν.)

[69] The passage is discussed by Miller (1982) pp. 105-6, Hasper (2003) p. 214 and Mendell (2007) pp. 16-8. Both Hasper and Mendell fail to address the question of how to secure the existence of divisions or limits. Miller does, but concerning time rather than path.

[70] In modern terms, the existence of *E* and *K* is established by an equivalent to Dedekind's principle, viz., the intermediate value theorem, being applied to the function which assigns to each place the time at which it is taken in passing.

[71] Remember that "the before and after is first in place", etc. (*Phys*. IV 11.219a14 ff.).

straightforward, the points of the first class are before the points of the second class. Hence, the continuity principle (T27) secures that there is a point *E* such that *B* gets to *E* at *G*.

My reconstruction of the argument corresponds to the version of the continuity principle in *Phys*. VII 4 mentioned earlier:

T27. There will be cases in which the circumference is larger than the straight line, and cases in which it is smaller. Hence, there will be also a case in which it is equal.[72]

In order to derive the application in *Phys*. VI 2, replace
- "cases" with *X* (i.e., a variable operating on points),
- "the circumference" with: the time it takes for *B* to get to *X*, and
- "the straight line" with *FG*.

In Dedekind's version (1872/1965, 10 = 1872, 11),

Zerfallen alle Punkte der Geraden in zwei Klassen von der Art, daß jeder Punkt der ersten Klasse links von jedem Punkte der zweiten Klasse liegt, so existiert ein und nur ein Punkt, welcher diese Einteilung aller Punkte in zwei Klassen, diese Zerschneidung der Geraden in zwei Stücke hervorbringt.

all points in the first class are before *E*, and all points in the second class are after *E* – which, again, entails that *B* gets to *E* at *G*.[73]

As in the second part of chapter 1, the movements involved in the procedure must be straightforward. Since no time metric is presupposed, uniformity of motion is no option. – But it should be noted that only if (i) a time metric is presupposed and (ii) the movements involved are required to be uniform, the application of the continuity principle boils down to the postulation of a fourth proportional.[74]

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[72] *Phys*. VII 4.248a24-25: ἔσται γὰρ μείζων καὶ ἐλάττων ἡ περιφερὴς | τῆς εὐθείας, ὥστε καὶ ἴση.
[73] That the continuity principle is required to fill an alleged gap in the proof of Euclid, *Elem.* I 1 was (in my view, falsely) claimed by Heath (1926) pp. 235-6, 242 etc. But the principle is employed in Bryson's quadrature of the circle (see Becker 1933, pp. 370 ff.; Mueller 1982, pp. 160 ff.; Hasper 2012, pp. 314-5). Aristotle's criticism of Bryson's proof (*SE* 11.71b13-18 etc.; *APo* I 9.75b37-76a3; on which Mueller 1982, pp. 150 ff. and Hasper 2012, pp. 307 ff.) amounts to disputing the value of the principle for geometry – but not, as it seems, for the mathematical account of motion, as in *Phys*. VI 2 and VII 4.
[74] For details and discussion, see again Heinemann (forthcoming).

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