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ARCHIMEDEAN INFLUENCES ON YAḤYĀ IBN ᶜADĪ*

BY

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*) ABBREVIATIONS:

- DIJKSTERHUIS, *Archimedes* (1987) = Eduard Jaan DIJKSTERHUIS, *Archimedes*, translated by C. DIKSHOORN, With a new bibliographic essay by W.R. KNORR (Princeton University Press, Princeton, 1987).
- ENDRESS, *Works* (1977) = Gerhard ENDRESS, *The works of Yaḥyā ibn ᶜAdī; an analytical inventory* (Reichert, Wiesbaden, 1977).
- ENDRESS, *Atomism* (1984) = Gerhard ENDRESS, *Yaḥyā ibn ᶜAdī* «Critique of atomism: three treatises on the indivisible part», *edited with an introduction and notes*, in *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 1 (1984) 155-179.
- KHALIFAT, *Yaḥyā* (1988) = Sahban KHALIFAT (= ḪALĪFĀT), *Yaḥyā Ibn ᶜAdī The Philosophical Treatises. A critical edition with an introduction and a study* (Department of Philosophy, Faculty of Arts, University of Jordan, Amman, 1988).
- RASHED, *Essais* (1984) = Jean ITARD, *Essais d'histoire des mathématiques*, réunis et introduits par Roshdi RASHED (Blanchard, Paris, 1984).
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- YOUSCHKEVITCH, *Les mathématiques* (1976) = Adolf P. YOUSCHKEVITCH, *Les mathématiques arabes (VIIIᵉ-XVᵉ siècles)*, Traduction par M. CAZENAVE et K. JAOUICHE, Préface de R. TATON (Vrin, Paris, 1976).

1) The mathematical explanation of Yaḥyā's text and the indication of its possible sources are due to Mauro NASTI DE VINCENTIS; the Arabic translation and the historical researches to Carmela BAFFIONI. We do not need to underline that the present work could not have been produced without the basic contribution of the historian of mathematics.

A. THE TREATISES ON ATOM AND GREEK MATHEMATICS

As is well known, Yaḥyā ibn ᶜAdī's writings on atomism have been widely studied by Gerhard Endress, who has produced an excellent critical edition and has pointed out their Greek sources, without ignoring the *Kalām* contribution as well[2].

The main goal of my research is to look for further sources of such treatises, possibly in the Greek, and mainly in the Arabic philosophical tradition. In spite of this, I will presently limit myself to call attention to a part of the «Treatise on the falsification of the thesis of those who maintain that bodies are composed of indivisible parts», which opens by the proof *ab absurdo* used by atomists to confute the infinite divisibility of the continuous. If such a division were possible, they argue, a mustard seed could be divided into so many parts, as would cover the whole of the celestial sphere. But as this is absurd, the infinite division of the continuous is absurd too. With regard to this, Endress notices that Yaḥyā uses here a famous *Kalām* argument[3], at the same time reelaborating Aristotelian thesis in a new perspective.

Right away, we have to underline that in Yaḥyā's arguments the division of the mustard seed in whatever number of parts is intended to cover the celestial sphere only if the mustard seed is taken as the unit of measure. Probably, the core of the polemic against atomists amounts just to this. But the historical ground of the argument could be recognized in Plato, *Resp.*, 525d9-e4, which reads as follows (and as a quite ironical remark against

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2) Cf. ENDRESS, *Works* (1977) and Idem, *Atomism* (1984). In his inventory (pp. 55-58), ENDRESS lists the following treatises: 1. *Maqāla fī tabyīn anna kull muttaṣil innamā yanqasim ilā munfaṣil wa ġayr mumkin an yanqasim ilā mā lā yanqasim*; 2. *Al-qawl fī anna kull muttaṣil fa-innahu yanqasim ilā ašyā' tanqasim dā'iman bi-ġayr nihāya*; 3. *Qawl fī l-ğuz' allaḏī lā yatağazza'* (according to al-Qifṭī's title; the title is lacking in the manuscript tradition); to these treatises a 4. *Maqāla fī tazyīf qawl al-qā'ilīn bi-tarkīb al-ağsām min ağzā' lā tatağazza'* is added.

N.1 corresponds to pp. 141-143 of the later edition by S. Ḫalīfāt [cf. KHALIFAT, *Yaḥyā* (1988)], where Endress' studies appear to have been missed); n.2 corresponds to pp. 275-279; n.3, according to the title indicated, has no correspondence in Ḫalīfāt 1988; n.4 corresponds to pp. 160-164 of KHALIFAT, *Yaḥyā* (1988). ENDRESS, *Atomism* (1984) gives in succession the texts of the first three treatises listed above (the second with the title: *Al-qawl fī anna kull muttaṣil fa-innahu munqasim ilā ašyā' tanqasim dā'iman bi-ġayr nihāya*, the third with the title: *Al-qawl fī l-ğuz' allaḏī lā yatağazza'*), limiting himself to cite the fourth in note (cf. p. 155, note 1). An examination of the treatises edited by Ḫalīfāt shows that this fourth treatise coincides with the one edited by Endress as n.3. Endress 1984 appears far better; therefore, we'll refer to it in the present work.

3) ENDRESS, *Atomism* (1984) 162-163 and notes, even for the sources.

mathematicians as well):

> «For you are doubtless aware that experts in this study, if anyone attempts to cut up the 'one' in argument, laugh at him and refuse to allow it, but if you mince it up, they multiply, always on guard lest the one should appear to be not one but a multiplicity of parts»[4].

On the other hand, Yaḥyā's confutation[5] reminds of some important geometrical themes; but, as far as we could see, this fact not only did not call Endress' attention, but seems unnoticed even by the historians of Arabic mathematics. Roshdi Rashed himself, whose researches in this field are a miliar stone, speaks of Yaḥyā's treatises on atomism only to remind that Endress found out in them[6] quotations from Proclus' *Institutio physica*[7].

So, Yaḥyā answers that the continuous is infinitely divisible only when unequal mutually related parts are spoken of [8]. And the frequently used verb *fanā*, «to be extinguished», referred either to the division into equal parts, or to the division into unequal and incommensurable parts as well, could make us believe that he has in mind the concept of «limit», when $1/2^n$, $n \geq 1$ and the limit tending to 0; anyway the concept of «limit» had been for a long time known to the Arabs[9].

Moreover, in Yaḥyā's explanation of the way how unequal but mutually related parts are generated,

> «in the sense that the continuous is divided, for example, into two halves, and each of its two halves into two halves, and in the same way everyone of the parts to which division arrives is divided into two halves, over and over again: in this way division lasts and multiplies» (176, 8-10),

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4) Cf. PLATO, *Republic II*, Books VI-X, Translated by P. SHOREY (Harvard University Press-Heinemann, Cambridge-London, 1987) 165.

5) It is preceded in KHALIFAT, *Yaḥyā* (1988) by pp. 160,11 -161,2, which Endress moves to the end of the treatise, considering these words a «marginal gloss». Actually, this passage at this point of the text is clearly incongruous; moreover, both Ḫalīfāt's and Endress' readings seem to need further emendations, though Endress' one is, by and large, preferable. But the discussion of this point is to be deferred to another occasion.

6) Precisely, in the treatise n.2 of Endress' inventory [ENDRESS, *Works* (1977)].

7) Cf. Roshdi RASHED, «Al-Sijzī et Maïmonide: Commentaire mathématique et philosophique de la Proposition II-14 des *Coniques* d'Apollonius», in *Optique et mathématiques, Recherches sur l'histoire de la pensée scientifique en arabe* (Variorum, London, 1992), n.XIII, p. 267, note 9.

8) ENDRESS, *Works* (1977), p. 58 recalls *Phys.*, III, 6. 206a17 and Simplicius' commentary, p. 491_{24}-492_{11}.

9) Cf. Roshdi RASHED, «Archimède dans les mathématiques arabes», in RASHED, *Optique* (1992), n.IX, p. 7 and ID., «Infinitesimal determinations, quadrature of lunules and isoperimetric problems», in RASHED (ed.), *Encyclopedia* (1996) 421.

we must understand the term *nuṣf*, «half», not according its literal meaning. In fact, to express $2^{1/2}/2$ in decimal notation requires a control over an infinite number of digits in order to ascertain that the two halves $2^{1/2}$ are actually equal to one another. But, what is more important, this statement seems to recall *Elem.*, X, 1[10] (Given two unequal magnitudes, if we take from the larger one a part bigger than its half, if we take from the remainder a part bigger than its half, and if we do this over and over again, a magnitude will remain, which will be smaller than the smallest of the proposed magnitudes). As is well known, this proposition is the hardcore of the so-called «exhaustion method», whose aim was to put off the actual infinite division, demonstrating that two surfaces or volumes «must» be equal because, if a difference existed, that should be smaller than any given magnitude[11] - and even smaller than 0-. The exhaustion method traces back to Eudoxus and consequently, to him traces back, most likely, *Elem.*, X, 1 as well.

Now, Yaḥyā adds that the division process affects only the dimension actually divided, leaving the others unchanged: so, if length is divided, the lengths which result from the division process cannot be equal to the original one; the same is to be said of breadth and depth. But the further two dimensions will continue to be equal to themselves before the object was divided. Therefore, Yaḥyā concludes, «it is possible... to imagine the multiplication of the parts till to a number whose amount is sufficient to cover very large extensions» (177, 4-5); of course, this is potentially, not actually valid[12].

B. The Ancient Mathematical Tradition Among the Arabs

In fact, one is not to be surprised by the «technical» echoes reminded till now, at least from the historical point of view. Since more than one century, in fact, Muslim mathematicians were interested in the main problems treated in the *Elements*, such as, e.g., the theory of parallels, the theory of proportions and the theory of second grade irrational numbers. Commentaries of Book V had been written already at the time of al-Ma'mūn, by al-ᶜAbbās ibn Saᶜīd al-Ǧawharī and by the observatory master, Abū l-Ṭāğib Sanad ibn ᶜAlī. The Baġdādian mathematician Abū ᶜAbdallāh Muḥammad

10) Euclides' work had been translated into Arabic at the beginning of IX century by al-Ḥaǧǧāǧ ibn Maṭar.

11) Cf. Jean Itard, *Essais d'histoire des mathématiques*, réunis et introduits par R. Rashed (Paris, Blanchard, 1984) 95 and Roshdi Rashed, «Infinitesimal determinations...», in Rashed (ed.), *Encyclopedia* (1996) 419.

12) This section of the treatise gives rise to very interesting remarks too, but we are again obliged to delay their discussion to an other occasion.

ibn ʿĪsā al-Mahānī (d. ca. 800) wrote commentaries on Books I, V, X and XIII[13], and took into consideration the theory of proportions attributed to Eudoxus[14], besides than to Euclid[15]. Moreover, he commented the Archimedean treatise on *The sphere and the cylinder*, and treated the determination of a segment of a parabola[16]. After al-Mahānī, the theory of parallels, founded on the famous Euclid's post. 5, was studied by al-Nayrīzī (d. 922 ca.). He based himself on Simplicius' witness, who probably transmitted the theory of parallels formulated by Aganis, a contemporary of his[17]. Further demonstrations of such a postulate were given by Ṯābit ibn Qurra, in a quite different way[18].

Also the knowledge of Archimedes in the Arabic world has been widely studied[19]. The treatise on *The measurement of the circle* was known - perhaps in a revised version - from the Bānū Mūsā, who also knew Eutocius' commentary of it. Recently, Roshdi Rashed has discovered that the same version was commented by the philosopher al-Kindī[20]. The second version, from Greek, was probably made by Isḥāq ibn Ḥunayn. Ṯābit ibn Qurra, on his own, has translated the treatise on *The sphere and the cylinder*, probably from Syriac; later, the work was retranslated from Greek by Isḥāq. On the contrary, the Arabs do not seem to have been acquainted neither with the treatises on *The quadrature of the parabola*, *The conoids and the spheroids*

13) Cf. YOUSCHKEVITCH, *Les mathématiques* (1976) 82.

14) Cf. YOUSCHKEVITCH, *Les mathématiques* (1976) 130 (we feel obliged to notice that the ideas here attributed to al-Ašʿarī are just opposite to the true ones. But perhaps that is due to the French translation, unless Youschkevitch's argument is actually a *reductio* argument).

15) Cf. YOUSCHKEVITCH, *Les mathématiques* (1976) 83.

16) R. RASHED, «Infinitesimal determinations...», in RASHED (Ed.), *Encyclopedia* (1996) 421.

17) Such a definition was similar to Posidonius' (I cent. b.C.) one.

18) In the *Maqāla fī burhān al-muṣādara al-mašūra min Uqlīdis* (Book on the demonstration of the famous Euclid's postulate) and in the *Maqāla fī anna al-ḫaṭṭayn iḏā uḫrigā ʿalā aqall min zāwiyatayn qā'imatayn iltaqayā* (Book on the fact that two lines which determine two angles less than two right angles meet together). We cannot know which of the two works precedes the other. Cf. YOUSCHKEVITCH, *Les mathématiques* (1976) 112-114, and also Boris A. ROSENFELD - Adolf P. YOUSCHKEVITCH, «Geometry», in RASHED (Ed.), *Encyclopedia* (1996) 463-467.

19) Beginning from M. CLAGETT's famous studies, on which cf. Carmela BAFFIONI, «Aspetti della dottrina di Archimede nella tradizione araba», paper presented at the Seminar on «Autori greci in lingue del Vicino e Medio Oriente» (Bologna, Oct. 13-14 1989), in print; cf. also YOUSCHKEVITCH, *Les mathématiques* (1976) 124 and note (and p. 131); Roshdi RASHED, «Archimède...», in RASHED, *Optique* (1992), n.IX; R. RASHED, «Infinitesimal determinations...», in RASHED (Ed.), *Encyclopedia* (1996) 419-420.

20) Cf. Roshdi RASHED, «Al-Kindī's Commentary on Archimedes' 'The Measurement of the Circle'», in *Arabic sciences and philosophy. A historical journal* 3 (1993) 7-53.

and *The spirals*, nor with that on the *Method of mechanical theorems.*

C. THE SO-CALLED «POSTULATE OF EUDOXUS-ARCHIMEDES»

But the possible Archimedean influences on Yaḥyā ibn ᶜAdī are even clearer in the following passage:

إنّه من قبل أن الفلك جسم متناهٍ والخردلة جسم متناه، ولكل واحد من جسمين متناهيين عند الآخر نسبة ما، يجب لذلك أن تكون للخردلة عند الفلك نسبة ما. فلنفرض تلك النسبة مثلا نسبة سطحٍ طوله مائة ألف جزء [و] عرضه مثل ذلك إلى مكعّب طوله مائة ألف جزء وعرضه مثل ذلك وعمقه مثل ذلك. وهو على مذهبك ممكن أن تشرح عمقه على جزء جزء فينقسم بالتشريح مائة ألف قسم. فإذا غُشِي جسم آخر، مساوٍ في الطول والعرض والسُمك لذلك الجسم المنقسم من هذه الأقسام، بستّة أقسام، غشتً هذه الأقسام الستّة جميع ذلك الجسم. ويبقى باقي الأقسام وهي أربعة وتسعون الف قسم تغشى مثل ذلك الجسم التي انقسمت منه خمسة عشر ألف جسم وستمائة جسم [وستّة] جسما وأربع جهات من جسم.

> «As the celestial sphere is a finite body, and the mustard seed a finite body as well; and as each of two finite bodies have a determinable ratio to one another, it is then necessary that the mustard seed also has a determinate ratio to the celestial sphere. Let's suppose that such a ratio is equal to the ratio that a hundred thousand lenght and breadth surface has to a hundred thousand length, breadth and depth cube. According to your opinion [namely, the atomistical], it is possible to cut its depth in slices, one part after another, untill when, through the cut, a hundred thousand parts are divided[21]. But if an other body - whose length, breadth and depth are equal to those of the body divided through these divisions - is covered with six parts, these six parts will cover the whole body, and the other parts - namely, ninety four thousand ones - will remain to cover something similar to that body whence fifteen thousand six hundred sixty six[22] bodies and four sides of a body have been divided»[23].

This passage cries out for elucidation. We immediately realize that Yaḥyā mentions the «six parts» intended to cover a square in order to introduce the question of irrationals: it is impossible to divide a square into six equal parts, whose side is commensurable to the side of the original square.

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21) In this figure, the depth is negligible because it is potentially possible to divide it a hundred thousand times (namely, infinitely).

22) Alouisius ENDRESS, 1984 emends through: «six». But, as we shall see, we should read «sixty six».

23) Yaḥyā IBN ᶜADĪ, *Treatise on the falsification of the thesis of those who maintain that bodies are composed of indivisible parts*, pp. 177,10 -178,3, ed. Endress.

Evidently, Yaḥyā postulates between the proposed bodies proportions like these:

$$\frac{100.000}{6} = \frac{94.000 + 6.000}{6} \quad \text{or} \quad \frac{94.000}{6} + \frac{6.000}{6} = \frac{100.000}{6},$$

where 94.000/6 gives just 15.666 2/3 - namely, the periodical number 15.666,(6) - which Yaḥyā expressed by the words «*ḫamsa ʿašra alf ǧismin wa-sitt mi'ati ǧismin [wa-sitta] ǧisman [sic] wa-arbaʿa ǧihāt min ǧism*», where «[*wa-sitta*]» is of course to be emended into «*wa-sitta wa-sittīn*», as we said before.

This passage of Yaḥyā's could happen to be based on the definitions of the ratio among magnitudes given at the beginning of *Elem.*, V. To be noticed that post.5 of this Book uses the exhaustion method, just like post.5 of the Archimedean treatise on *The sphere and the cilynder*[24], which reads as follows: «Of unequal lines, unequal surfaces, and unequal solids the greater exceeds the lesser by an amount such that, when added to itself, it may exceed any assigned magnitude of the types of magnitudes compared with one another»[25].

This postulate looks as a reminder of the postulate of Eudoxus, namely: with regard to two unequal magnitudes A and B, where A<B, it is assumed that there exists a number *n* having the property that *n*A>B, because A will finally become bigger than B. A is divided into two unequal parts, the smallest into two more and so on, so to get *n* parts and take the smallest, which satisfies the requested conditions[26]. Such a postulate was demonstrated from *Elem.*, I, 35 (On dividing one of two straight line segments into two equal parts a sufficient number of times, one gets a segment smaller than the smallest of the two). A long tradition relates to Eudoxus (408-355 or 390-337?) *Elem.*, V, whence the propensity to name the axiom at issue «postulate of Eudoxus-Archimedes». But, according to Jean Itard, both the parallel postulate, and the more basic one on the Archimedean magnitudes, date back to the III century at the most[27]. Furthermore, Dijksterhuis underlines that the postulate of Eudoxus is different from the postulate of Archimedes, which

24) Cf. RASHED, *Essais* (1984) 140.

25) Cf. DIJKSTERHUIS, *Archimedes* (1987) 146.

26) The only exception to the rule, the mixed angles; cf. on this Mauro NASTI DE VINCENTIS, «Atomismo e geometria nelle argomentazioni anti-atomistiche di Ibn Ḥazm, Šahrastānī e Faḫr al-Dīn al-Rāzī», in Carmela BAFFIONI, *Atomismo e antiatomismo nel pensiero islamico*, con un'Appendice di M. NASTI DE VINCENTIS (Napoli, Istituto Universitario Orientale, 1982) 277-300, part. pp. 291-293, and RASHED, *Essais* (1984) 66.

27) Cf. RASHED, *Essais* (1984) 66 and 93.

could be resumed like this: if two magnitudes satisfy the axiom of Eudoxus in respect of each other, their difference also satisfies this assumption in respect of any magnitude of the same kind homogeneous with both[28].

Now, we have already hinted at the fact that such an assumption aimed to exclude the existence of actual infinitesimals[29], and we are aware that Eudoxus denied the atomistic conceptions of time and space in mathematics, just like Aristotle had denied them in philosophy. But if till to Aristotle (cf. e.g. *De cael.*, I, 6.273a) Eudoxus' statement had looked like a «common sense» one, the exception of the mixed angle, formed by an arc of circumference and its tangent at a given point, discussed in *Elem.*, III, 16 showed that it was rather a definition - of the Archimedean magnitudes -[30], and a postulate as well - because it required that the magnitudes considered were Archimedean ones -. Beside than in the treatise on *The sphere and the cylinder*, this axiom is stated, as a postulate, also in *The quadrature of the parabola* and in *The spirals*.

So, in his argument Yaḥyā seems to refer to Archimedean magnitudes. And if our historical knowledge does not hinder such a hypothesis, we cannot know how aware he was of his own position.

D. Conclusions

No doubt that, from the historical point of view, the mathematical themes here recognized are consistent with the acquired tradition, but they possibly place Yaḥyā ibn ᶜAdī in an at least partially new position.

Moreover, he is a further witness of the knowledge of Eudoxus in the Arabic world; but, above all, Yaḥyā's arguments display a radically new attitude in front of the ancient world. In fact, till then only the product, but not the sum, subtraction or division of heterogeneous magnitudes was accepted; in the West, the innovative step will be taken only by Galileus (of course, as regards the division of heterogeneous magnitudes); Yaḥyā, on the contrary, explicitly speaks of both division and subtraction of surfaces from volumes.

Finally, we would remind the procedure of Archimedes' *Method*, where each surface is considered as composed with parallel lines which fill it, and

28) Cf. Dijksterhuis, *Archimedes* (1987) 148. As is well known, a long discussion arose on the best reading of this postulate.

29) Cf. Dijksterhuis, *Archimedes* (1987) 149.

30) I.e., rectilinear segments, areas, volumes, rectilinear angles, and furthermore arcs, odd areas, weights and times.

are considered as the infinitesimal constituent elements of the figure; the same is to be said of surfaces in reference to the solid they will constitute; in such a perspective, lines and surfaces are «indivisibles»[31]. Well, just this procedure seems to be implied in Yaḥyā's argument, in spite of the fact that, as we saw, according to scholarship the *Method* was not known to the Arabs. Instead, to Eudoxus *Elem.*, XII is traced back - just on the ground of a passage of the *Method* -[32]. Here, the infinitesimals question is also treated, but the Archimedean method of body's composition in parallel layers is not used[33]. This is, evidently, a point on which Yaḥyā ibn ᶜAdī differs from Eudoxus. Is it also possible to reopen the question of the widespreading of the *Method* in the Arabic world?

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31) On «indivisibles» of this kind Bonaventura Cavalieri, in the XVII century, built his own geometry.

32) Cf. RASHED, *Essais* (1984) 94-95 and 87, respectively.

33) Cf. RASHED, *Essais* (1984) 135 and 139.

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