Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research xxx (2009) xxx–xxx
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Reflections on the antikythera mechanism inscriptions

Maria K. Papathanassiou

Faculty of Mathematics, National and Kapodistrian University of Athens, Athens, Greece

Received 10 January 2008; received in revised form 30 April 2008; accepted 2 May 2008

Abstract

A close look at the fragmentary inscriptions of the Antikythera Mechanism published by Freeth et al. [Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J.H., Tselikas, A., Magkou, E., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockley, P., Malzbender, T., Gelb, D., Ambrisco, W., Edmunds, M.G. Decoding the Antikythera mechanism: investigation of an ancient astronomical calculator. Nature 444 (7119), 587–591, 2006] reveals some elements, which could help to decode its function and use. The Back Door Inscription seems to give a detailed description of some external parts of the instrument and the related instructions for their use. We especially refer to the term «ecliptic» as compared to that in *Ars Eudoxi* and other papyri and inscriptions. The Back Plate Inscription seems to give instructions for the proper orientation and use of the instrument. The Front Door Inscription refers to the stationary points of planetary motion, but only two planetary names have been read, that of Venus and Mercury, as far as we know. After a study of the works of Alexandrian scholars Ptolemy, Theon, Paulus and Heliodorus regarding the stationary points of planetary motion, we arrive at the following conclusion: it seems very likely that the Antikythera Mechanism has been constructed apart from other uses (a) for the observation of the Sun, the Moon and the stars; (b) to simulate the longitudinal motion of the Sun, the Moon and the planets, and (c) in the case of Mercury and Venus the instrument could also show their stationary points and the retrograde arc between them; here we present additional arguments to support the view that this is also true for the three outer planets. As far as the technical knowledge underlying the construction of Mechanism's gear trains is concerned, the last (eighth) book of Pappus's *Collection,* includes the basic notions and theorems for such constructions, known from the earlier works of Archimedes.

Keywords: Antikythera mechanism; Astronomical instruments; Greek astronomy

1. Introduction

The publication of the article «Decoding the Antikythera Mechanism» by Freeth et al. (2006) has revived the interest of scholars for further research into the related topics of the early history of science, especially that of astronomy, and technology. This unique artifact found in the Antikythera shipwreck by Greek sponge-fishers in 1900 has been also studied in the 20th century. Here we refer only to the first comprehensive and extensive publication, that of Price (1974); full references to more recent publications of M. Wright (1995, 2002, 2003, 2005a,b,c, 2006a,b), A. Bromley (1990, 1993) and other scholars are to be found in the article of Freeth et al. (2006).[1]

In his article Price (1974) published the inscriptions on the saved parts of the Antikythera Mechanism and tried to trace the early history of gearing based on conventional X-radiographs taken by Charalambos and Emily Carakalos. Freeth et al. (2006) using the latest achievements of contemporary technology, as surface imaging and high-resolution 3-dimentional X-ray tomography, achieved to propose a better reconstruction of the Antikythera Mechanism and read many more letters of the engraved inscriptions on the saved parts. Our comments on these inscriptions are based on their publication.

E-mail address: mpapatha@math.uoa.gr

[1] Other source material is listed in Appendix.

0273-1177/$36.00 © 2009 Published by Elsevier Ltd. on behalf of COSPAR.
doi:10.1016/j.asr.2009.10.021

2. The Back Plate Inscription

2.1. The greek text of the Back Plate Inscription

```
1                 Ι Π Ο
2               ΙΚ ΟΛ Ι Τ
3               ΙΝ Ο Ν
4 Α Π Ο Χ Ο       Ο
5   Δ Ε Κ Α Τ   Ξ Ω   ΝΤ Α Ν
6   Λ Ι Β Α           Ν   ΧΙ Π
7   Λ    Μ Α
8                 Ν
9
10        Π Ρ Ο
11        Ι Σ Τ ΩΝ Τ Α Σ
12          Κ Α Τ Α Λ Η
13          Π Ρ Ο Σ Α Π Η Λ
14            Ω Τ Η Ν Ω
15             Λ Η Ν Τ Ω
16              Χ Ρ Ω Ν Ι Α
17               Π Υ   Ο
18                Ι Ο
//
19
20            Φ
21           Ρ Ι Ι Σ
22           Τ Α Α Δ
23          Ν Ο Τ Ο Ν
24          Κ Α Ι Α Ρ Η Σ
25         Σ ΗΦ Α Ρ Ο Σ
26        Λ Ε Ν Τ Η Ν Κ
27         Σ Α ΦΥ Λ Α Ξ Α Σ
28       Ι Λ Α Μ Ε Λ Α Ν
29          Χ 2  Π Κ Ζ Φ
30   Α Π Ο Ν Ο Τ Ο Υ Π Ε Ρ Ι
31     Ι Σ Π Α Ν Ι Α Σ Δ Ε Κ Α
32                Δ Υ Σ Α Ν
33
```

(*from* Freeth et al., 2006).

2.2. The points of the horizon

This small fragment of the Back Plate Inscription offers some important information regarding the points of the horizon, which obviously were used for orientation. The name ΛΙΨ in accusative ΛΙΒΑ (l.6) implies that a proposition (obviously ΠΡΟΣ) precedes it, namely [ΠΡΟΣ] ΛΙΒΑ meaning [TOWARDS] SOUTHWEST. The same could be said for the name ΝΟΤΟΣ in accusative ΝΟΤΟΝ (l. 23); it implies that the proposition ΠΡΟΣ precedes it, namely [ΠΡΟΣ] ΝΟΤΟΝ, meaning [TOWARDS] SOUTH. On the other hand, the expression ΑΠΟ ΝΟΤΟΥ(l. 30) signifies FROM SOUTH. In this context we attempt to read ΠΡΟΣ ΑΠΗ-ΛΙΩΤΗΝ, meaning [TOWARDS] EST, the (l.13) ΠΡΟΣΑΠΗΛ[Ι], as well as ΩΤΗΝ in following l.14, namely [ΠΡΟΣ ΑΠΗΛΙ]ΩΤΗΝ.

We should remember that the names of the points of the horizon coincide with those of the winds but their arrows indicate opposite directions. Namely, we orientate towards a direction, for example to the «North», seeing towards this point on the horizon; on the contrary, a «North» wind has an opposite direction, as it comes from the North and blows towards the South point of the horizon. The Back Plate Inscription seems to give instructions for the orientation of the instrument so that it can be properly used in the greatest part of the Oikoumene, namely the inhabited world. Expressions like «towards Apeliotes» indicate a direction on the horizon towards which we should orientate rather than that of a wind, as winds are named according to the point they come from.

To support our view we cite some examples from Greek papyri: http://www.perseus.tufts.edu/cache/perscoll_DDBDP.html.

The Duke Databank of Documentari Papyri, Pap. Batav.: Textes grecs, démotiques et bilingues, No 3, (Date: 109 BC; Location: Memnoneia PSI9,1021), lines 12-16 ΝΟΤΟΥ ΓΗ, ΒΟΡΡΑ ΓΗ, ΑΠΗΛΙΩΤΟΥ, ΛΙΒΟΣ ΓΗ.

Pap. Alex.: Papyrus grecs du Musée Gréco-Romain d'Alexandrie, Inv. 414 (Date: III saec; Location: ? SB 1. 4308), l. 3 ΑΠ'ΑΠΗΛΙΩΤΟΥ, l. 7 ΕΚ ΤΟΥ ΠΡΟΣ ΝΟ-ΤΟΝ.

2.3. The parapegma

The term «parapegma» originally meant an inscription, exhibited, like a sundial, for public use. It contains a list of fixed star phases and associated predictions for the weather for a whole year. Because of the irregular fluctuations of the Greek lunar calendars the dates of the phases in the civil calendar of the current year were shown on pegs, which were inserted in little holes drilled into the stone beside the lines of the text. Beside the stone inscriptions a literary form of «parapegmata» (plural) developed of which the Geminus's Parapegma is the earliest extant example. The text gives, exactly as the inscriptions, a list of consecutive fixed star phases and weather prognostications. The role of the holes, which represent consecutive days, is now taken over by a day-by-day progress of the sun. We should point out that the information given by a parapegma-inscription «fixed» in a site depends upon the geographical latitude of the site as far as the fixed star phases are concerned, while weather predictions depend upon «local» climatic conditions. On the contrary, a parapegma of literary form, carried by a traveler who changes places, cannot be properly used either for fixed star phases or weather predictions.

Consequently, our fragmentary text engraved on a portable instrument could not be a «parapegma» of literary form, as it saves the names of three directions on the horizon — namely, those of East, South and South-West— and not those of winds. An argument pro this view is the beginning of the text of the *Ars Eudoxi* (*Pap. Paris. 1*, col.1) describing the «path of the Sun» from the winter solstice to the summer solstice and vise versa through the vernal and fall equinoxes respectively, with reference to the points of the horizon (either ΕΙΣ «towards» or ΑΠΟ «from» them): North, South, East, South-West. Another argument pro this view is a Diagram of Horizons (ΚΑΤΑΓΡΑΦΗ ΟΡΙΖΟΝΤΩΝ) in the *Cod. Paris. gr. 2394*. The related explanatory text is as follows: «By means of this [diagram] we know for every latitude how many degrees north or south of the Equator the starting point of every zodiacal sign is located».

3. The Back Door Inscription

3.1. The greek text of the Back Door Inscription

1 1 ΤΑΥΤΗΝΔ
2 2 Δ ΙΔΥΠΟΛΛ
3 3 ΥΠΟΔΕΤΟΝΤ
4 4 ΑΤ
5 5 Ε
6 6
7 7 Ο
8 8 ΙΡΜΟΣ
9 9 ΑΚΡΟΥΔ
10 10 ΜΕΝΟ
11 11 Μ
12 12 ΟΛ Ν
13 13 ΥΠΟΛΑ
14 14 ΟΥΔ ΣΦΑΙΡΙΟΝΦΕΡΕ
15 15 ΠΡΟΕΧΟΝΑΥΤΟΥΓΝΩΜΟΝΙΟΝΣ
16 16 ΦΕΡΕΙΩΝΗΜΕΝΕΧΟΜΕΝ
17 17 ΤΟΣΤΟΔΕΔΙΑΥΤΟΥΦΕΡΟΜΕΝ
18 18 ΤΗΣΑΦΡΟΔΙΤΗ ΕΡΟΥ
19 19 ΤΟΥ ΣΨΟΡΟΥΙΕ ΕΡΕΤΑΝ
20 20 ΓΝΩΜΩ ΚΕΙΤΑΙΧΡΥΣΟΥΝΣΦΑΙΡΙΟΝ
21 21 ΗΛΙΑΚΤΙΝ ΥΠΕΡΔΕΤΟΝΗΛΙΟΝΕΣΤΙΝΚΥ
22 22 ΥΑΡΕΣΑΥΡΟΕΝΤΟΤΟΔΕΔΙΑΠΟΡΕ
23 23 ΕΘΟΝΟΣΤΟΔΕΔΙΑΠΟΡΕΥΟΜΕΝΟΥ
24 24 ΙΝΟΝΟΥΚΥΚΛΟΣΤΟΔΕΣΦΑΙΡΙΟΝΦ
25 25 Μ Ε ΤΟΥΚΟΣΜΟΥΚΕΙΤΑΙΣΦ
26 26 ΜΕΝ ΣΤΟΙΧΕΙΑΠΑΡΑΚΑ Ν
27 27 ΛΥΤΑΤΑΙΣΑΣΠΙΔ
28 28 Α ΟΤΩΝΔΙΑΩ ΣΤΩΝΜΕΝ
29 - ΝΟΜΗΤΗΙΕΛΙΚΙΤΜΗΜΑΤΑΣΛΕ
30 - ΤΑΙΣΚΑΙΕΞΑΙΡΕΣΙΜΟΙΗΜΕΡΑΙΚ
31 - ΧΟΝΣΤΗΜΑΤΙΑΔΥΟΠΕΡΙΤΥΜΠΑΝ
32 - ΠΡΟΕΤΡΗΜΕΝΑΣΤΗΜΑΤΙΑΤΗΜ
33 - ΑΤΩΝΤΡΗΜΑΤΩΝΔΙΕΛΚΕΣΘΑΙ
34 30 ΟΜΟΙΑΩΣΤΟΙΣ
35 31 ΦΥΕΣΠΟΙΗ
36 32 ΚΑΙΣΥΜΦΥ
37 33 Τ ΠΑ
38 34
39 35 Ε ΟΥ
40 36 ΕΝΛΧΠΑΝ Ε
41 37 ΜΗΝΟΘΕΝΕΞΗΛ
42 38 ΤΗΣΠΡΩΤΗΣΧΩΡΑΣ
43 39 ΜΟΝΙΑΔΥΟ ΩΝ ΤΑΑΚΡΑΦΕ
44 40 ΤΕΣΣΑΡΑΔΗΛΟΙΔΟΜΕΝΤ
45 41 ΣΑΙ ΝΤΗΣ OCL ΙΘLΤΟΥ
46 42 ΟΣΕΙ ΕΙΣΑ ΣΚΓ ΣΥΝΤΕΣ
47 43 ΙΟΝΤ ΟΣΔΙΑΙΡΕΘΗ Η ΟΛΗ
48 44 ΔΟΙΕ ΕΓΛΕΙΠΤΙΚΟΙΣ
49 45 ΙΟΜΟ ΤΟΙΣ ΕΠΙΤΗΣΕ
50 46 ΧΡΟΝΦΕΡΕ ΤΑ
51 47 ΠΙΝ ΕΝΤ

(*from* Freeth et al., 2006).

This inscription seems to give a detailed description of some external parts of the instrument (e.g. the small golden sphere, the spiral and the pointers) and the related instructions for their use.

3.2. The ecliptic

The engraved Greek word is ΕΓΛΕΙΠΤΙΚΟΙΣ, i.e. the dative plural of the epithet ΕΓΛΕΙΠΤΙΚΟΣ or ΕΓΛΕΙΠΤΙΚΟΝ. We can immediately see the use of letter Γ instead of K (ΕΚΛΕΙΠΤΙΚΟΙΣ). We note that the interchange of letters Γ and K before the letter Λ in Greek language is well known from Hellenistic times until now (ΕΚΛΕΙΧΩ → ΕΓΛΕΙΧΩ → ΕΓΛΕΙΦΩ → ΓΛΕΙΦΩ). Let us now cite some cases from Greek papyri and inscriptions:

Firstly, we cite two cases occurring in Greek papyri from Egypt (http://www.perseus.tufts.edu/cache/perscoll_DDBDP.html):

The Duke Databank of Documentari Papyri, Pap. Batav.: Textes grecs, démotiques et bilingues, No 3 (Date: 109 BC; Location: Memnoneia PSI9,1021): l. 31 ΕΓΛΕΙΠΕΙΝ, l. 34 ΕΓΜΙΣΘΟΥΝ.

Secondly, we cite some examples occurring in Greek inscription from the SE Aegean Islands and the coast region of Asia Minor, (http://epigraphy.packhum.org/inscriptions/):

Rhodian Peraia 24, b.1, l. 29 ΕΓΛΕΙΠΟΝΤΟΣ, l. 32-33 Τ]ΟΥ ΕΓΛΕΙ[ΠΟΝΤΟΣ. Caria, IK Knidos I 231 (turn of 3rd/2nd cent. BC), l. 30 ΕΓΔΟΣΙΝ. Caria, IK Knidos I 221, Kalymnos, ca. 300 BC, A[2], l. 37 ΕΓΔΙΔΟΝΤΩ, l. 44 ΕΓ ΔΑΜΟΣΙΟΥ, l. 48 ΕΓΜΑΡΤΥΡΗΣΑΝΤΩ, l. 53-54 ΕΓΜΑΡΤΥΡΗΘΕΙΣΑΣ, also lines 59, 60, 61, 63–64 and others. Cos, Paton-Hickss 10, ca. 202/201 BC, l. 23 ΕΓΔΟΝΤΩ.

We should point out that the above inscriptions are written in the Doric dialect of Greek language spoken in those regions, while the Greek papyri from Egypt are written in common Greek language like the Attic dialect. Moreover, the only one Greek astronomical text in which occur the word ΕΓΛΕΙΨΙΣ (eclipse) and the related verb ΕΓΛΕΙΠΩ [instead of ΕΚΛΕΙΨΙΣ and ΕΚΛΕΙΠΩ resp.] is that known as ΕΥΔΟΞΟΥ ΤΕΧΝΗ (*Ars Eudoxi*, namely *The Art of Eudoxus*). The use of Γ instead of K appears also in all derivates of the word throughout the above text, which is *not* written in the Doric dialect. We also note the use of the word ΕΓΜΑΘΕΙΝ instead of ΕΚΜΑΘΕΙΝ (verb «study») in the beginning of the text. On the other hand, neither the word «ecliptic» nor its derivates occur in Hipparchus's Commentary on the phenomena of Aratus and Eudoxus, even in the citations from their texts, nor in the works of Rhodian astronomers Attalus (2nd cent. BC) and Geminus (1st cent. BC).

The *Art of Eudoxus* is saved in the *Papyrus Parisinus 1*, which was found in 1778 near Gizeh and was published in Rome 10 years later. The date of the papyrus is deduced from a remark in column XXII, namely that according to Eudoxus and Democritus the winter solstice falls on the 20th or 19th of the Egyptian month Athyr. If we allow the interval for the solstice to range between December 28 and 24 we obtain for Athyr 19/20 a date between – 196 (197 BC) and – 173 (174 BC). This would be the date the papyrus was written. A linear scheme for the variation of the length of the daylight is based on the parameters for Lower Egypt (minimum duration = 10 h, maximum duration = 14 h). Neugebauer points out the close parallels of this text with *Papyrus Hibeh 27*, which was written about – 300 (301 BC); this suggests a similar date for the original version of the *Eudoxus papyrus*. This would be close to the time of Callippus who is mentioned near the end of the text for his parameters of the lengths of the seasons (Neugebauer, 1975, pp. 599–600, 686–689).

Taking into consideration that none Greek word of the inscriptions on the saved parts of the Antikythera Mechanism is written in the Doric dialect, and the above linguistic evidence as far as the term ΕΓΛΕΙΠΤΙΚΟΣ is concerned, it seems very likely that the Antikythera Mechanism has been designed and constructed in Alexandria of Egypt.

The text of the *Art of Eudoxus* (cols. V and IX) says that the planets describe «spiral paths» because their distance from the fixed poles of the celestial sphere is variable. But spiral paths hold also for the Sun and the Moon. According to this text, the synodic period of Venus is 1 year 3 months 4 days (=459 days) and that of Mercury is 3 months [2] 6 days. Although there is no word about retrogradations, as Neugebauer points out, it is well known that Eudoxus of Knidos, has introduced the theory of the homocentric (but not coaxial) spheres in order to explain the forward and retrograde motion of the planets and to calculate their retrograde arc between the two stationary points. On the other hand, it is clear that the text of the *E. papyrus* is only a general and elementary introduction to the celestial phenomena. But we should stress that according to this work attributed to Eudoxus the distinction between fixed stars and planets is based on the preservation of the similarity of the order, namely the fixed stars preserve the triangles, the squares, the circles and the straight lines during the revolution of the celestial sphere (col. VII). We easily recognize here the principles of similarity, fully exposed in Books V (on ratios and proportions) and VI (similarity of schemes) of Euclid's *Elements*, attributed to Eudoxus and we note that the stereographic projection introduced by Hipparchus is based on these principles.

3.3. Pointers, gears and trunnions

The text of the Back Door Inscriptions mentions «pointer(s)» (ΓΝΩΜΟΝΙΟΝ and ΓΝΩΜΟΝΙΑ, lines 15, 20, 43) and two preperforated (ΠΡΟΕΤΡΗΜΕΝΑ) trunnions (ΣΤΗΜΑΤΙΑ) around a gear (ΤΥΜΠΑΝΟΝ)» (lines 31, 32). The gear and the two preperforated trunnions remind us Heron's of Alexandria (1st cent. AD) description of a train of two unequal toothed wheels and the two copper trunnions mounted on the major one of them (*Dioptra*, Section 3). A century later, Ptolemy describes the construction of an astrolabe as well as that of an instrument for the observation of the moon (*Mathematical Syntaxis*, Book V, chap. 1 and 12). Much later Proclus Diadochus (5th cent. AD) describing the construction and the use of an astrolabe (*Hypotyposis astronomicarum positionum*, chap. 6) uses the term ΠΗΓΜΑΤΙΑ ΕΧΟΝΤΑ ΔΙΑΥΓΙΑ («small attachments having peepholes») – instead of ΠΡΟΕΤΡΗΜΕΝΑ ΣΤΗΜΑΤΙΑ – to denote the perforated trunnions mounted at right angles and on diametrical positions. This terminology continues until late Byzantine times as we can deduce from the astronomical work of the 14th century Byzantine scholar Theodorus Meliteniotes (*De astronomia libri III*, dating in 1361); for example Book I (lines 75, 107).

4. The Front Door Inscription

4.1. The greek text of the Front Door Inscription

Ο
ΟΔΕΗΟΣ
ΟΣΑΠΟΣΤΗΜΑ
Δ ΟΝΕΞΑΡΧΗΣΑ
Ε ΣΠΟΜΕΝΑΟΔΕ
ΟΥ ΟΕΣΠΟ ΑΠΟΚΑΤΑΣΤΑΣ
Π ΑΣΤΟΥΔΑΠΟΚ ΟΤΑΣΝ ΝΑΤΑΙΣΟ
ΛΟΠΡΟΣΤΟΝΗΛΙΟΝΣΟ ΠΟΔΕ
ΙΑΞΙ ΑΛΙΣΑΣΚ[ΑΙ]ΠΡΟΣΑΓΕΙΝΕΠ[Ι]ΣΗΣΤΟΝΗΛ[ΙΟΝ]
[ΠΡ]ΟΣΑΓΕΤΑΙΕΠΙΤΟΝ[ΗΛ]ΙΟΝΕΛΑΣΣΟΝΑΣΤΗΡΙΓΜΟΙΣΤΥΓΧΑΝΗΑΠΟΣ
[ΠΡ]ΟΣΑΓΕΙΠΡΟΣΤΟΝ[Η]ΛΙΟΝΕΩΣ ΗΣΕΙΟΝΚΑΙΣΥΝΟΔΟΝΑ
ΕΠΙΤΟΜΕΓΙΣΤΟΝΕΠΟΜΕΝΟ ΟΕΝΑΛΛΑΙΣΗΜΕΡΑΙ[Σ]
[ΣΤΗΡΙΓ]ΜΟΝ[ΩΣ]ΟΠΡΟΗΓ[Ο]ΥΜΕΝΟΣ ΑΠΟΣΤ ΑΛΘ
ΑΣ ΕΝΗΜΕΡΑ[Ν]ΠΟΙΕΙΠ[ΡΟ]ΕΝΟΣΕΙΣΤΗ[Ν]ΚΕΠ
[ΔΙ]ΑΣΤΗΜΑΤΟΣΠ[Ρ]ΟΣΑ [Ο]ΠΡΟΣΤ
ΚΗΣ ΕΙΟΣΧ[Ε]ΠΙΤΕΜ ΧΑ
ΟΣΙΗΤΟΝΗΛΙΟΝΗΑΦΡΟ[ΔΙΤΗ] ΗΝΟΙΣΝ
ΣΤΗΠΡΟΣΑΓΕΙΠΑΣΙΝΓΩΝΙΑΙΣ
ΟΙ [ΗΜΕΡΑΣ]ΠΡΟΣΑΓΕΙΤΗΝ ΠΙΠΕΤΑ ΝΑΚΑ ΣΑ Ε
ΕΣΠ ΗΜΕΡΑΣΚΑΙΥΠΟΛΕΙΠΕΤΑΙΜΕΧΡΙΤΗΣΕΩΙΑΣΣΤ
Η[ΜΕΡ]ΑΙΤΜΗΜΕΡΑΣΣΟΝΟΗΟΝΟΤΟΥ Λ ΑΚΜΗ
ΑΝΙΣΑΤΟΝΕΠΙΣΟΝΕΧΩΝΣΤΗΡΙΓΜΟΝΕΠΙΣΧΩΝΑΠΟΤΟΥΗΛΙΟΥΝ ΕΣΛΙ
ΑΕΣ ΑΙΠΙΣΞΕ ΗΛ[ΙΑ]ΚΗΝΠΑΡΑΤΕΙΝΕΤ[ΗΝ]ΑΠΟΣΤΑΣΙΝ ΕΣΑΠΟ
ΡΕΣΑΣΞΕΗΛΙΑΚΗΝΕΠΕΤΕΙΝΕΝΤΕΣΣΑΡΑΚ/ΕΝΑΕΥΔΟΜΟΝΚΑ
ΝΕΞΗΜΕΡΑΣΗ ΓΕΝ[Ε]ΣΕΩΣΕΝΕΝ ΕΧ ΕΩΑΝΚΑΤΑΛΟ
ΕΑ ΕΙΝ Π ΔΙΑΣΤΑΣΙΝΣ ΗΜΕΡΑΙΣΜΕΝΜΕΓΑΛΑΙΣ
ΑΚΑΙΔΩΔΕΚΑΤΗΜΟΡΙΟΣΚΑ ΑΦΑΙΛΕΤΗΝΥΠΟΛΟΙΠΟ[Ν]
ΑΜΟΝΕΞΑΠΟΤΟΥΕΣΠΕΡΙΝΟΥΕ ΕΧ ΣΚΑΙΥΠΟΛΟΙΠΟΝ
ΑΝΤ Μ ΗΜ ΕΝΧΡΟΝΩ ΑΠΑΝΑΙΟΝ ΗΜΕΡΑΙΣΤΟ
ΕΑ ΣΕΠΑΓΕΙΣ ΡΛΘ ΕΠΙΤΟΝΗΛΙΟΝΤΟΝΣΤΗΡΙΓΜΟΝ [Ε]
ΟΟΝΟΜΑΗΜΕΡΑΣΛΑΠΡΟΗΓΕΙΤΑΙΗΜΕΡΑΙΣΤΟ
ΝΑΝΑΤΟΛΗΣΕΙΝΑΙΟΗΛΙΟΣΜΗΜΕΡΑΣΠΑΛΟΝ
ΑΝ ΑΗΜΕΡΑΝΓΙΝΕΤΑΙΗΠΕΡΑΙ ΕΙΣ
[ΗΜ]ΕΡΑΣΣΕΙΣΑ ΗΜΕΡΑΙΑΠΟ ΟΕ
ΡΑΣ ΙΝΕ Μ
ΤΗ

(*from* Freeth et al., 2006).

4.2. Stationary points

The Front Door Inscription, the most preserved and extensive, refers almost exclusively to the two kinds of stationary points (ΣΤΗΡΙΓΜΟΙ) of planetary motion. That moment, as far as we know, no more than two names of planets are read, namely those of Venus (ΑΦΡΟΔΙΤΗ) and Mercury (ΕΡΜΗΣ). From a first look at it we immediately recognize it as a fragment related to the theory of the retrograde motion of the planets. Let us focus in line 11 (the reading of underlined letters is dubious):

[ΠΡ]ΟΣΑΓΕΤΑΙΕΠΙΤΟΝ[ΗΛ]ΙΟΝΕΛΑΣΣΟΝΑΣΤΗΡΙΓΜΟΙΣΤΥΓΧΑΝΗΑΠΟΣ

This line is translated by Freeth et al. (2006) as «... brought upon the Sun the minor stationary point ⟨s or 200⟩ then occurs distance».

Although the two consecutive words ΕΛΑΣΣΟΝΑ ΣΤΗΡΙΓΜΟΙΣ (if the reading is correct) look as if the epithet ΕΛΑΣΣΟΝΑ is attributed to ΣΤΗΡΙΓΜΟΙΣ, there is no such term like ΕΛΑΣΣΩΝ ΣΤΗΡΙΓΜΟΣ (minor station) in the theory of retrogradation. Eudoxus of Knidos (4th cent. BC) was the first astronomer who formulated a cinematic theory – that of the homocentric spheres – to explain this phenomenon. Claudius Ptolemy (2nd cent. AD) in the first chapter of the twelfth Book of his *Mathematical Syntaxis* exposes the theory of retrogradation and the necessary conditions so that a point is a stationary one according to both theories (that of epicycles and that of the eccentric cycles). Ptolemy states that the proof is due to other mathematicians and especially to Apollonius of Perga (end of the 3rd cent. BC). We cite Apollonius's condition for the stationary points in both models:

In the epicyclic model a planet located at a point P of its epicycle, appears stationary to an observer O (who is located at the center of the deferent) if and only if (OP/PT) = (Vp/Vc), where Vp is the angular velocity of the planet on its epicycle with respect to the direction OC and Vc the angular velocity of C as seen from O with respect to some fixed direction, while OP is the distance of P from O and PT half the chord PQ, if we produce OP. The point P is called the «first» stationary point; a «second» station occurs in the position symmetric to the first with respect to the radius OC. In the eccentric model a planet located at a point P is stationary seen from $\overline{O}$, when ($\overline{O}$P|PS)=(Vp/Vm) where Vm = Vc + Vp is the angular velocity of the center M of the eccenter with respect to some fixed direction from $\overline{O}$ (Neugebauer, 1975, pp. 267–268).

Ptolemy uses the epithet ΕΛΑΣΣΩΝ («minor», in nominative case) or ΕΛΑΣΣΟΝΑ (in accusative case) as he refers either to the «minor ratio» (ΕΛΑΣΣΟΝΑ ΛΟΓΟΝ) or to the «minor angle» (ΕΛΑΣΣΟΝΑ ΓΩΝΙΑΝ) [res. the «major ratio» (ΜΕΙΖΟΝΑ ΛΟΓΟΝ) or the «major angle» (ΜΕΙΖΟΝΑ ΓΩΝΙΑΝ)], as he compares segments, triangles or speeds (namely the speed of the planet on the epicycle to that of the center of the epicycle on the eccentric cycle). Ptolemy distinguishes between the two kinds of stationary points (ΣΤΗΡΙΓΜΟΙ); namely, between the «first» (ΠΡΩΤΟΣ) and the «second» (ΔΕΥΤΕΡΟΣ) or «the other one» (ΕΤΕΡΟΣ). Especially the astrologers Dorotheus of Sidon (1st cent. BC–1st cent. AD), Thrasyllus of Alexandria (1st cent. AD) and the famous Vettius Valens of Antiochia (2nd cent. AD) in his *Anthologiarum libri ix* (Book 1, chap. 18), refer to the stationary points using the same terminology and naming them as «first» and «second». The tradition of this terminology continues in the works of the 4th cent. AD astrologers, namely Hephaestion of Thebes, Paulus of Alexandria (*Elementa Apotelesmatica*, chap. 15) and Heliodorus of Antiochia (*In Paulum Alexandrinum Commentarium*, chap. 12) and the mathematician Theon of Alexandria who explain the use of Ptolemy's *Handy tables* for the calculation of the kind of the planetary motion (forward motion before the first station, first stationary point, retrograde motion before the second station, second stationary point, forward motion after the second station). This is done by means of a comparison of the results of the entries in the related tables, namely if the calculated number is «major» or «minor» than those in the tables, reveals whether the planet has (or not) arrived in the first station or retrogrades or he has already passed the second station.

We should point out that a planet reaching the «first» stationary point and starting its retrograde motion seems to reduce its speed, while being in the «second» stationary point the planet seems to accelerate its forward motion. Consequently, our fragmentary text could contain terms as «minor» and «major» stationary points, as a shortened expression referring to the «first» and «second» stationary points respectively, while implying the planets' different speeds on them.

4.3. Length of the retrograde arc and the outer planets

According to Ptolemy, the «distance» (or length) (ΑΠΟΣΤΗΜΑ) of the retrograde arc between the «first» and the «second» stationary points, can also be «medium», «maximum» or «minimum». As the text is a fragmentary one and many letters are missing from both sides, it seems very difficult any attempt for the reading of the text either «vertically» or «horizontally». But even so, it is clear that some lines include references to time intervals expressed in days. In this case an investigation regarding arcs and days of retrograde motion seems to be very useful for the understanding of the text. For example, line 31 is read as follows:

ΕΠΑΓΕΙΣ⟨Ρ<u>ΛΘ</u>⟩ΕΠΙΤΟΝΗΛΙΟΝΤΟΝΣΤΗΡΙΓΜΟΝ

This line is translated by Freeth et al. (2006) as «brings on ⟨139⟩ the Sun the stationary point».

The number ΡΛΘ (=139) is a dubious reading as the forms of the letters Θ and Η are close enough. Could it be an Η? Then the number ΡΛΗ(=138) is the number of days of Saturn's retrograde motion in case of the «mean distance» (in «maximum distance» the retrogradation lasts 140 and 2/3 days, while in «minimum distance» its duration is 136 days), as stated by Ptolemy (*Syntaxis*, XII, ch. 2).

Apart from the above remark regarding Saturn's retrogradation, if it is correct, there is an additional argument pro the hypothesis that the Antikythera mechanism could have been used also for the calculation of the motion of «all» planets. This argument is the reading of line 19, if it is correct and we understand properly its meaning:

ΣΤΗ<u>Π</u>ΡΟΣΑΓΕΙΠΑΣΙΝ<u>ΓΩ</u>ΝΙΑΙΣ

This line is translated by Freeth et al. (2006) as *«brings upon every ⟨angle⟩»*.

We should remember that the three outer planets – Mars, Jupiter and Saturn – form «every angle» with the Sun, as seen from Earth; namely, their «elongation» is measured from 0° to 180° east or west of the Sun. Consequently, it is very likely that line 19 refers to one of the outer planets; and if it is so, we could well suppose that references to the outer planets have been lost with the missing parts of this inscription.

4.4. The front dial fragment

The Front Dial fragment (D. de Solla Price, 16-20, 1974) saves the names of 2 months of the Egyptian calendar, ΠΑΧΩΝ (*Pachon*) and ΠΑ[ΥΝΙ] (*Payni*) in the outer annu-

Please cite this article in press as: Papathanassiou, M.K. Reflections on the antikythera mechanism inscriptions. J. Adv. Space Res. (2009), doi:10.1016/j.asr.2009.10.021

lus and those of two zodiacal signs, ΧΥΛΑΙ (Libra) and [ΠΑΡΘ]ΕΝΟΣ (Virgo) in the inner annulus. Taken into account the numerous local Greek calendars with particular names of months taken from local festivals, the different dates of the first day of the calendar and the changing number of its days every year, we well understand that a local Greek calendar were not a good choice for an astronomical device. On the other hand, the Egyptian calendar with a standard number of 365 days (12 months of 30 days and 5 supplementary days at the end of the yearly cycle) was characterized by its simplicity and regularity. For this reason the astronomers, from Hellenistic times to the 16th cent., used it in their calculations. Consequently, it was the only appropriate choice for the Antikythera Mechanism, an astronomical device of high precision. Could it be an additional argument pro a possible construction of the Mechanism in Alexandria?

5. On gear trains

The structure of the gear trains in the Antikythera mechanism shows an already evolved technology as far as gear wheels are concerned. As this mechanism dates in the second half of the second century BC, we present some additional arguments in our effort to elucidate a little more the history of technology underlying its construction.

Our main source is Pappus of Alexandria (4th cent. AD) who in the last (eighth) book of his *Collection* (Ed. F. Hultsch, Weidmann, Berlin, vol. 3 (1878)) treats some topics of mechanics, stating clearly that these theorems have been proved by the «ancients» and that he would like to cite the most easily to be found and formulate them in a shorter and clearer manner than before (p. 1028, lines 6–10). He says that «according to the mechanicians of Heron's school, the science of mechanics consists of a theoretical and a practical part, the former one including geometry, arithmetic, astronomy, and physics» (p. 1022, lines 13–17). Among the mechanicians should be included the «sphere makers», who «construct a model of the heavens [and operate it] with the help of the uniform circular motion of water». Pappus cites the view that «Archimedes of Syracuse mastered the principles and the theory of all these branches» of mechanics, as well as that of Carpus of Antioch that «Archimedes wrote only one book on a mechanical subject, that on sphere-construction» (p. 1026, lines 2–12). Let us only remind Cicero's description of Archimedes's «celestial globe» which could represent the motion of the sun and the moon and the divergent movements of the planets with their different rates of speed (*De re publica*, I. xiv. 21–22).

As far as Archimedes of Syracuse (287–212 BC) is concerned, we should not wonder for his special interest in sphere-construction as a model of the heavens. His father, Pheidias, was a known astronomer and Archimedes himself knew very well the works of earlier and contemporary astronomers, especially their measurements regarding the relative sizes and distances between the Earth, the Moon and the Sun, and the size of the Cosmos. In his *Sandreckoner* Archimedes criticizes a proportion regarding the size of the Cosmos in relation to that of the Earth's orbit given by Aristarchus's of Samos in his work *On the sizes and distances of the Sun and the Moon*; Archimedes also cites the famous passage referring to Aristarchus's heliocentric hypothesis (Archimedes, *Arenarius*, ed. C. Mugler, vol. 2, Les Belles Lettres, Paris, 1971, 134–157; here p. 135, l. 3 – p. 145, l.8).

As the mathematician who measured the circumference of the circle and an inventor of many machines, Archimedes would have been interested in the construction and use of toothed wheels, and consequently in the formulation of the related theory of gear wheels and their trains. Pappus cites some «old» theorems regarding the relations between the diameters, the number of teeth and the speed of trains of two gear wheels.

Pappus states clearly that Archimedes in his work *On balances*, as well as Philo (*Belopoeica*) and Heron (*Dioptra*, Section 37; *Mechanicorum fragmenta*, Book I, fr. 1), «demonstrated that the major circles (wheels) are predominant in relation to the minor ones, if they roll round the same center». In another theorem cited by Pappus, it is given a train of two gear wheels A and B, where the ratio of the diameter of A to the diameter of B equals the ratio of the number of teeth of A to the number of teeth of B; he then shows that the ratio of the speed of A to that of B equals the ratio of the number of teeth of A to that of teeth of B (chap. 25, p. 1102ff.)·

He further shows that «the ratio of the circumferences of the wheels equals that of their diameters»: namely, if AB and CD are the diameters of the two circles (wheels), then the ratio of the circumference of AB to the circumference of CD equals to the ratio of the diameter AB to the diameter CD (chap. 20, p. 1104ff.). Finally, he proves that «given a wheel with a known number of cogs or teeth, to find the diameter of a second wheel to be engaged with the first and having a given number of teeth.» He adds that «this proposition is generally useful and in particular for machine makers in connection with the fitting of cogged wheels» (p. 1028, lines 21–29; chap. 27, p. 1106ff.).

I am of the opinion that we should always remember Pappus's statement regarding the «ancients» who have formulated and proved the mechanical theorems and his direct references to Archimedes, the greatest Greek geometer, astronomer and founder of the science of mechanics. The traces of the early history of the Antikythera Mechanism seem to lead us back to Archimedes at least as far as its gear trains are concerned.

6. Conclusions

In the present article we have just touched a few questions and problems arising from the published study of Freeth et al. (2006). In the attendance of new results from their further studies we did attempt this approach to the subject. Let us now express our final assumptions:

Taken into account that Archimedes did correspond with Eratosthenes of Kyrene, head of the library attached to the Museum of Alexandria, it seems very likely that Archimedes communicated all his works to him, even those on the science of mechanics, as we can deduce from his famous «Method», where he uses mechanical methods to find a solution before he treats the problem purely theoretically. His works were saved during many centuries and were available for study to later mathematicians and mechanicians of Alexandria – as Heron and Pappus – and of other Greek towns, as Eutocius of Ascalon, Isidorus of Milet and Anthemius of Tralles (the two architects of Haghia Sophia in Constantinople in the 6th cent. AD). If Archimedes's works survived so many centuries later, no wonder if mechanicians of his time or a little later could have applied his theorems in the construction of gear trains for specific use.

On the other hand, the famous astronomer Hipparchus of Nicaea in Bithynia was active in Alexandria and Rhodes Island (in Aegean Sea) between the years 162 BC and 127 BC, according to the relative citations in Ptolemy's *Mathematical Syntaxis* (III, 1; V, 3, 5; VI, 5, 9; VII, 2). From the 17 recorded observations made by Hipparchus only the last three (in 128 and 127 BC) have been surely made in Rhodes, while it is not certain for another two (in 141 and 135 BC); most of the remaining recorded observations have been made in Alexandria (Neugebauer, 1975, p. 276). Finally let us venture the following hypothesis: the astronomical theories of Hipparchus during the years of his activity in Alexandria have been combined with the necessary technical knowledge provided by Archimedes's works (and available to Alexandrian astronomers and mechanicians) in this sophisticate astronomical device very likely constructed in Alexandria. The answer to the question: «Were it possible that this exceptional device has been made for and used by Hipparchus himself?» is left to the reader of this article.

References

Bromley, A. G., 1990. The Antikythera Mechanism, Horological Journal 132, 412–415, 1990.

Bromley, A. G. Antikythera: an Australian-Made Greek Icon!, Bassernet, vol. 2, no. 3, June 1993, Basser Department of Computer Science, University of Sydney, 1993.

Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J.H., Tselikas, A., Magkou, E., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockley, P., Malzbender, T., Gelb, D., Ambrisco, W., Edmunds, M.G. Decoding the Antikythera mechanism: investigation of an ancient astronomical calculator. Nature 444 (7119), 587–591, 2006.

Neugebauer, O. A History of Ancient Mathematical Astronomy. Springer, Berlin, 1975.

Price, de Solla D. Gears from the Greeks. The Antikythera mechanism – A calendar computer from ca. 80 BC, vol. 64, Part 7. Transactions of the American Philosophical Society, NS, Philadelphia, 1974.

Wright, M.T. A planetarium display for the Antikythera mechanism. Horological Journal 144 (5 and 6), 169–173, 193, 2002.

Wright, M.T. Epicyclic gearing and the antikythera mechanism, Part I. Antiquarian Horology 27 (3), 270–279, March, 2003.

Wright, M.T. The Antikythera mechanism: a new gearing scheme. Bulletin of the Scientific Instrument Society 85, 2–7, 2005a.

Wright, M.T. Epicyclic gearing and the Antikythera mechanism, Part II. Antiquarian Horology 29 (1), 51–63, 2005b.

Wright, M.T. Counting months and years: the upper back dial of the Antikythera mechanism. Bulletin of the Scientific Instrument Society (87), 8–13, 2005c.

Wright, M.T. The Antikythera mechanism and the early history of the moon-phase display. Antiquarian Horology 29 (3), 319–329, 2006a.

Wright, M.T. Understanding the Antikythera mechanism. In: Proceedings Second International Conference on Ancient Greek Technology, Technical Chamber of Greece, Athens, pp. 49–60, 2006b.

Wright, M.T., Bromley, A.G., Magkou, E. Simple X-Ray Tomography and the Antikythera Mechanism, PACT 45 (1995). In: Proceedings of the Conference Archaeometry in South-Eastern Europe, pp. 531–543, April 1991.

Appendix: Other source material is listed below

Archimedes, Arenarius. In: Mugler, C. (Ed.) Les Belles Lettres, vol. 2. Paris, pp. 134–157, 1971.

Claudii Ptolemaei opera quae exstant omnia. In: Heiberg, J.L. (Ed.), Teubner, Leipzig, vol. 1.1, 1898; vol. 1.2, 1903.

Commentaire de Théon d'Alexandrie, sur le livre III de l'Almageste de Ptolemée; tables manuelles des mouvements des asters, éd. Halma, Paris, 1822.

Eudoxi ars astronomica qualis in charta Aegyptiaca superset (Pap. Paris. 1). In: Blass, F. (Ed.), Kiel, pp. 12–25, 1887.

Heliodori ut dicitur in Paulum Alexandrinum Commentarium. In: Boer, Ae. (Ed.), Teubner, Lipsiae, 1962.

Heronis Alexandrini opera quae supersunt omnia, Teubner, Leipzig, vol. 2.1, pp. 256–298 Mechanicorum fragmenta (Nix, L., Schmidt, W. (Eds.)), 1900; vol. 3, pp. 188–314; Dioptra (Schöne, H. (Ed.)), 1903.

Pappi Alexandrini collectionis quae supersunt. In: Hultsch, F. (Ed.), vol. 3. Weidmann, Berlin, 1878.

Pauli Alexandrini Elementa Apotelesmatica. In: Boer, Ae. (Ed.), Teubner, Leipzig, 1958.

Proclus Diadochus, Hypotyposis astronomicarum positionum. In: Manitius, C. (Ed.), Teubner, Leipzig, 1909 (repr. Stuttgart, 1974).

Strabo. The Geography. In: Jones, H.L. (Ed.) Loeb, vol. ii. London, 1923.

Theodorus Meliteniotes, De astronomia libri III (Tribiblos Astronomique). In: Leurquin, R. (Ed.), Gieben, I, Amsterdam, 1990; II, Hakkert, Amsterdam, 1993.

Vettii Valentis Antiocheni anthologiarum libri novem. In: Pingree, D. (Ed.), Teubner, Leipzig, 1986.

Available from: <http://epigraphy.packhum.org/inscriptions/>.

Available from: <http://www.perseus.tufts.edu/cgi-bin>.

Available from: <http://www.perseus.tufts.edu/cache/perscoll_DDBDP.html>.

Available from: <http://www-history.mcs.st-andrews.ac.uk/Extras/Pappus_on_mechanics.html>.

Please cite this article in press as: Papathanassiou, M.K. Reflections on the antikythera mechanism inscriptions. J. Adv. Space Res. (2009), doi:10.1016/j.asr.2009.10.021