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1
General Preface to the Inscriptions

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The Antikythera Mechanism Research Project

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Abstract

This is the prefatory paper to a series which presents the surviving text inscriptions on the Antikythera Mechanism. The structure of the mechanism and the history of the reading of the inscriptions are briefly reviewed. The methods used by the Antikythera Mechanism Research Project to image the inscriptions —computed tomography and polynomial textual mapping— are outlined. The layout of the inscriptions is described, and the dimensions of the mechanism deduced to allow the space available for inscriptions to be estimated. General conventions and notations are provided for the presentation of the inscriptions.

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1.1 Introduction

The Antikythera Mechanism was a geared device displaying chronological cycles of the Sun and Moon, and motions and phenomena of the heavenly bodies, made somewhere in the Hellenistic world in or before the early 1st century BC[1] Its mechanical components and display facings were made of bronze alloys, while the casing was wooden.[2] Such devices are mentioned in a number of classical sources, sometimes under the figurative name *sphairai* (Latin *sphaerae*) since they functioned as a representation of the cosmic sphere.[3] More recent designation has been as a "planetarium" and a "calendar computer," and while neither expression is entirely adequate by itself, the two taken together provide a good description of the Mechanism's functions. The fragments of the Antikythera Mechanism (Fig. 1.1) were recovered just over a century ago by sponge divers from the wreck of a Greco-Roman ship that sank, probably not long after 70 BC, off Antikythera, a small island between Crete and the Peloponnese.[4] They have been preserved, ever since their discovery, in the National Archeological Museum in Athens. Through the work of many people, most notably Albert Rehm, Derek de Solla Price, Allan Bromley, Michael Wright, and researchers belonging to and collaborating with the Antikythera Mechanism Research Project (AMRP), we currently have fairly secure understanding of a substantial portion of the inner workings as well as the outer displays of the Mechanism.

References to other papers in this series take the form IAM followed by the paper number and, where relevant, section number. Figures are designated by the paper number followed by the figure number (e.g. Fig. 1.1), and there are ten supplementary illustrations designated S1 etc.

1 See Freeth *et al.* 2006 for work up to that date, and continuing bibliography at http://www.antikythera-mechanism.gr/bibliography.

2 Wright 2011, 7-10.

3 See Edmunds 2012, 2014, Jones 2016, Price 1974. "Calendar computer" is Price's final designation (in the subtitle of Price 1974); "planetarium" was proposed by Rehm 1905, 27.

4 For an account of the salvage of the wreck see Throckmorton 1970, 113-168 and Tsipopoulou, Antoniou, & Massouridi 2012.

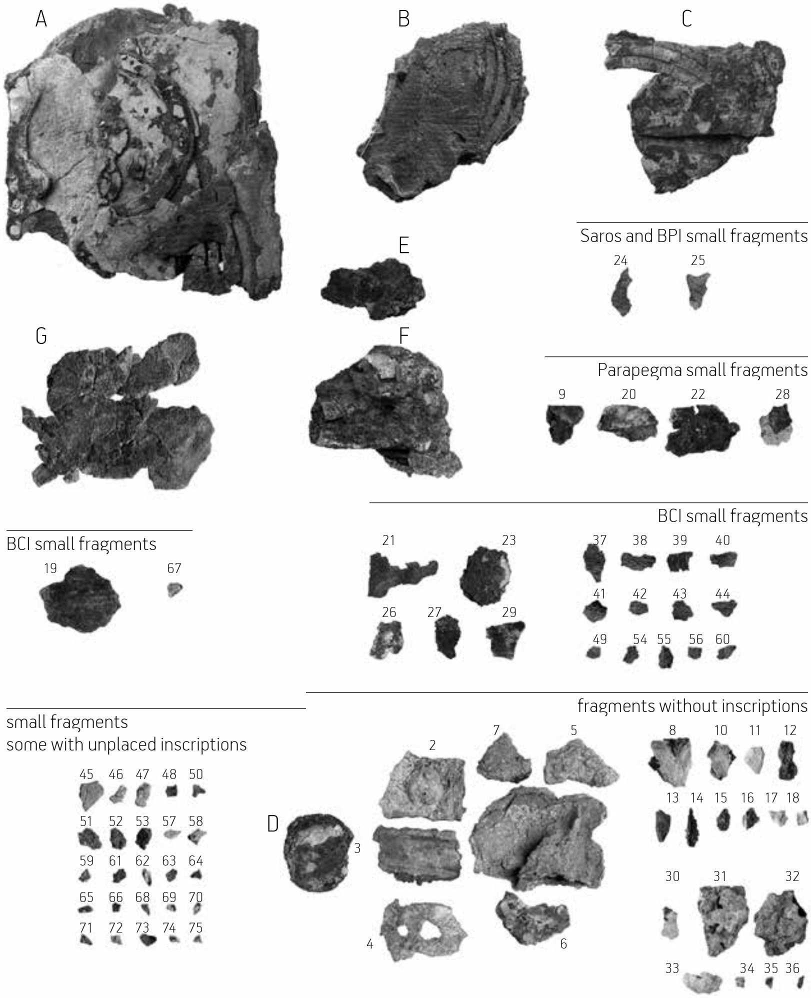


Figure 1.1: *The 82 known fragments of the Antikythera Mechanism (Images: National Archaeological Museum, Athens, photographer: Kostas Xenikakis, copyright Hellenic Ministry of Culture and Sports/Archaeological Receipts Fund)*

Its exterior was box-shaped, roughly 330 mm tall, 180 mm wide, and something more than 80 mm from front to back. There has been some disagreement about the structure of its casing, but we believe the physical evidence and other considerations support the description we give here.[5] Fig. 1.2 gives an impression of the exterior (front and back) of the Mechanism, emphasizing the bronze plates which carry the inscriptions.

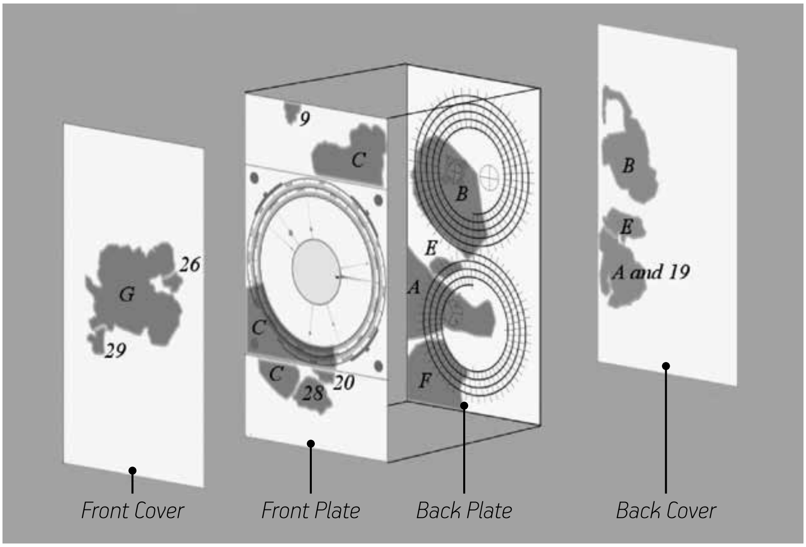


Figure 1.2: *Reconstructed schematic of the front and back plates and covers of the Antikythera Mechanism, omitting the back dial pointers. The view is from the front, assuming transparency through the Mechanism. The letters and numbers indicate the approximate*

5 Price deduced the basic two-face structure of the Mechanism in 1958, having discovered how Fragments A and B fitted together and, less exactly, their original spatial relationship to Fragment C (Price 1959, 62-63). Previous attempts at reconstruction relied on speculation and on erroneous ideas about the fragments' original configuration. Price's 1959 drawing of the reconstructed Mechanism (Price 1959, 62) shows only the inner casing, so that the Back Plate projects some way above and below the casing; subsequently (Price 1974, 17) he proposed a boxlike structure with outer casing enclosing a smaller inner frame for the gears. Recent reconstructions have mostly resembled Price's second design (though not in all details), but M.T. Wright's models, following his interpretation of the remains of the casing visible in early photographs as well as the surviving physical evidence, are more like Price's earlier conception, with the approximately square casing for the gearwork stepped out at its back into a shallow wooden frame that encloses and backs the Back Plate (Wright 2011, 11-12 and fig. 1.1 on p. 1 and 1.2 on p. 4). Reasons for believing that the Mechanism's front face had the same dimensions as its back face are presented in *IAM* 3.

original positions of the surviving fragments
The Mechanism was accompanied by two metal plates that may have functioned as front and back covers that would have been removed to expose the Mechanism's displays. A knob or crank to drive the device projected from the box's right side as seen from the front. The front face was divided vertically into three plates: a square central plate, and above and below it two rectangular plates. Most of the square plate was taken up by a circular dial with multiple pointers radiating from the center to a pair of concentric graduated scale rings, while the rectangular plates had no dials. The rear face, on the other hand, was a single metal plate bearing several dials, with one pointer to each dial. The basic principle of the Mechanism's operation was that the rotary input on the side, probably driven by hand, represented the progress of time — approximately $4\frac{2}{3}$ rotations of the input giving one rotation (representing a solar year) of the Mechanism's largest gear. The pointers revolved around the dials on the front and back faces to show diverse chronological cycles related to the Sun, Moon and the concurrent motions of the heavenly bodies through the zodiac.

The viewer would have also seen Greek texts inscribed on and around the dials as well as on the detached cover plates. These inscriptions were written in tiny capital letters (letter height ranging from about 1.2 mm to about 3.0 mm), similar in style to those used in the Hellenistic period for inscriptions on stone. During the first years following the discovery of the fragments in 1902, the inscriptions attracted as much attention as the mechanical features, for it was hoped not only that their contents would explain the nature of the Mechanism, but also that study of the style of lettering would furnish a dating of the Antikythera shipwreck. Current dating by the epigraphy suggests that it is characteristic of the second half of the second century BC but does not exclude a date as early as say 200 BC or as late as the wreck date**.** Ceramics and coins found in the wreck establish a far more precise date for the shipwreck (and hence at least a *terminus ante quem* for the Mechanism) than paleographical analysis of the Mechanism's inscriptions can offer.[6] But the inscriptions have proved crucial for understanding of the function of the Mechanism: in the first instance by establishing that it was connected with astronomy; subsequently by yielding several key words and numbers that complemented and filled gaps in the physical evidence for reconstructing the gearing; and most recently by clarifying the astronomical and cultural meaning of the data that the Mechanism's dials displayed.

At the outset formidable obstacles stood in the way of reading the inscriptions. What

6 Ceramics: Weinberg et al. 1965, Kavvadias 2012. Coins: Yalouris 1990, Oikonomidou 2001, Tselekas 2012. The current consensus places the wreck around 70-50 BC; datable Pergamene tetradrachm coins set a *terminus post quem* of 76 BC, while the ceramics appear to be characteristic of dates ranging from the 80s through the 50s. On the paleography of the Mechanism's inscriptions see *IAM* 2.3-2.4**.**

survives is a shattered and crushed fraction of the original whole, and all the longer inscriptions are more than half missing, an irreparable loss. Pressure and impacts displaced components and bent and distorted surfaces that once were flat. Centuries of immersion in seawater caused the bronze plates to be corroded to the point that little or no free metal remains, and their surfaces came to be caked over with layers of a hardened mixture of corrosion materials and sedimentary matter. Adjacent components stuck together, concealing inscribed surfaces.

The first efforts to read the texts, made within days of the discovery within the Museum, were limited to a few words and word fragments that happened to be on the outside of pieces that were in more or less the condition that they had come out of the sea. At that time and for many decades after, the only prospect for recovering more text was through physical alteration of the fragments aimed at undoing the sea's work by separating fused components and cleaning off the accreted matter. Such conservation work was carried with noteworthy success in about 1905 and again in 1953. However, large parts of the inscriptions could not be transcribed either on account of surface damage or because they were hidden inside the fragments.

Earlier published and unpublished readings of the texts were superseded by a set of transcriptions published by Price in 1974.[7] Price, whose own knowledge of Greek was slight, obtained the collaboration of the epigrapher George Stamires during his visit to the National Archeological Museum in 1958, and the texts that appear in his monograph are primarily Stamires's work with occasional interventions by Price himself. On the whole this collection represented a considerable advance on anything that had appeared before, with respect to both the quantity of text read and the accuracy of the readings. Nevertheless Price conceded that there were only two of the longer inscriptions of which one could "read and understand more than a scattered word or two".[8]

The research program on the Mechanism begun by A. Bromley and M.T. Wright in the late 1980s and subsequently continued by Wright alone was primarily devoted to study of the physical and mechanical features of the fragments.[9] As well as autopsy, Bromley and Wright carried out together with H. Mangou of the Museum's Department of Physical and

7 Price 1974, 18 and 46-51. For a detailed review of transcriptions preceding the present series of papers, see *IAM* 2.2.

8 Price 1974, 48-49.

9 Wright 2005, 13 n. 10 reports that he and Bromley made limited efforts to read the inscriptions but invited the collaboration of an epigrapher; this epigrapher's work seems not to have been completed.

Chemical Research a series of radiographs of the fragments in 1990.[10] Like the radiographs that H. Karakalos had prepared for Price in 1971-1972,[11] these were made for the sake of revealing the internal mechanical structure of the fragments. To obtain information about the relative depth of components within fragments, stereographic radiography and linear motion tomography (LMT) were employed. As applied to the Mechanism's fragments, LMT involved radiating a fragment while the fragment and the film were moved continuously in such a way that the parts of the fragment lying in a plane appeared in sharp focus in the radiograph while other planes were blurred. Wright, Bromley, and Magou found that the tomographic images were capable of capturing traces of inscriptions both on exposed surfaces and on surfaces embedded within the fragments.[12] Although they were unable to read any of the embedded lines of text, they expressed confidence that, with refined technique, LMT could be applied successfully to the inscriptions.

In 2005 the Antikythera Mechanism Research Project in collaboration with the National Archeological Museum investigated the 82 currently known fragments of the Mechanism with high resolution photography, reflectance imaging (Polynomial Texture Mapping, or PTM) carried out by a team from Hewlett-Packard Corp.,[13] and microfocus X-ray computed tomography (CT) by X-Tek Systems Ltd. (now part of Nikon Metrology).[14] The data and images obtained by these nondestructive techniques greatly enhanced the legibility of the exposed inscriptions, and made it possible for the first time to read writing on surfaces embedded inside fragments. The first publication arising from this project, in 2006, included provisional texts, much more extensive than those of Stamires and Price, of several of the inscriptions.[15] A second paper in 2008 was devoted to the inscriptions on the Mechanism's back dials, only a small part of which had been read by Stamires and Price.[16] Revised and expanded texts of some of the inscriptions, based on the AMRP data, have since appeared in other publications.[17]

The series of papers that the present article introduces contain revised editions and in-depth studies of all the Mechanism's inscriptions. Some (the Front Dial Inscriptions and Parapegma Inscription) have not been revisited in print since Price's 1974 *Gears from the Greeks*; the new editions significantly augment Price's texts with parts of the inscriptions that have

10 Wright, Bromley, and Mangou 1995, Mangou 2012.
11 Price 1974, 12-13.
12 Wright, Bromley, and Mangou 1995, 542.
13 http://www.hpl.hp.com/research/ptm.
14 http://www.xtekxray.com/applications/antikythera.html.
15 Freeth et al. 2006, Supplementary Information 5-14.
16 Freeth, Jones, Steele, & Bitsakis 2008.
17 See *IAM* 2.2.

become visible or legible for the first time through X-ray CT, which has the ability to isolate text in "slices" through the fragments and has contributed several thousand additional text characters. The surviving parts of three other extensive inscriptions, the Back Plate Inscription, the Front Cover Inscription, and the Back Cover Inscription, were transcribed in 2006, but prolonged study of the CT and PTM data gathered in 2005 has led to substantial progress in recovering continuous and intelligible texts for them. The transcriptions in the present series of papers are based almost exclusively on computer-assisted visualization derived from the data produced in 2005. Use of these techniques has made it possible to see the remains of the inscriptions with much greater clarity on a computer screen than can be attained through autopsy or conventional photography. Where inscribed surfaces have been lost or degraded since 1902, however, older photographs and transcriptions have occasionally proved useful as primary evidence for the readings.

The 2006 AMRP paper's discussion and texts of the inscriptions were described as a work-in-progress, with the promise of a more definitive publication in due course, of which the present series is the fulfillment. This prefatory paper appears under the names of nearly all the authors of the 2006 paper (who constituted the original AMRP) along with researchers who joined in the inscriptions research since 2006. This recognizes the fundamental contribution of the collaborators from the National Archeological Museum, Hewlett-Packard, X-Tek, and the original academic team in obtaining the data and the provisional readings on which the new editions and analysis of the inscriptions are built. The remaining papers are authored by the researchers who, studying the relevant inscriptions since 2006, are responsible for the editions, translations, and new interpretations. Mike Edmunds has acted as the independent coordinating editor for the series, and does not claim to have contributed directly to the detailed reading or decipherment of the inscription texts.[18]

18 The plan for the present publication of the inscriptions by the AMRP was agreed in June 2012. One of the original members, Dr. Tony Freeth, subsequently withdrew from that agreement in October 2012 and has published related material independently elsewhere (Freeth 2014). See also the acknowledgements in the present paper.

1.2 Reading the Inscriptions with CT and PTM Imaging

X-ray Computed Tomography (CT) creates a high-resolution 3D density map of a sample. The "density" is not quite material density, although it follows the material density closely, but it more closely follows the electron density, as it is the electrons in the sample which absorb the X-rays. Chemical differences are therefore also shown, with higher atomic number elements like iron, tungsten and gold appearing much denser than, say, aluminum or silicon.

A CT scan builds this 3D density map from a large number of X-ray images, or radiographs, from many different angles, collected as the sample is rotated very slowly on a turntable. In each radiograph the intensity, or grey value, is reduced by the amount and density of material along the line of travel of the X-rays. If the X-ray source is small then the sample can be placed close to the source to create a magnified image on the detector. In this way small details in the sample can be seen in the images. After the scan finishes, the radiographs are reconstructed into a 3D volume which contains 3D pixels, or "voxels" whose grey level represents the X-ray density at that position, the density and path length effects having been separated.

Penetrating large fragments of corroded bronze while still maintaining high resolution require special measures. First the X-rays need enough energy to be able to penetrate a long distance of dense material. Secondly the size of the emission point of X-rays needs to be kept small so that magnified images of the sample remain sharp. The X-ray source used to inspect the fragments of the Mechanism was powerful enough to penetrate 50 mm of solid steel and yet still see details down to 25 microns (0.025 mm). The resolution of the CT scans of the Mechanism's fragments ranged from 40 to 100 microns.[19]

The CT volume is analysed either by rendering it as a 3D object which the user can turn, move, clip and change the lighting on, or by extracting 2D grayscale slice images from the volume at any orientation and position. Since the acquisition geometry is very well known, the size of the voxels is also known to great precision allowing accurate measurements to be taken from the data.

The primary means of visualizing the contents of the CT volumes of the Mechanism's fragments was the software VGStudio MAX (by Volume Graphics). This software enables one to choose any axial direction through the volume and generate two-dimensional grayscale images of planar slices perpendicular to that axis. For examining an inscribed

19 A few brief details of the imaging and computing were given in Edmunds and Freeth 2011, while Ramsey 2012 discusses the CT more fully and includes a non-technical account of the method.

surface, one normally will use an axis perpendicular to the desired region of the surface, adjusting the level of the slice so that it cuts through the engraved traces or the accretion layer that preserve a negative impression of the engraving. The inscribed surfaces are seldom exactly planar, and the clarity of the letters varies unpredictably with the slicing level so that one sometimes gets best results with a "deep" slice near the level of the bottoms of the engraved grooves, sometimes with a slice closer to the plate's surface. Hence one typically sees only a small patch of an inscription clearly at a time, and to read it in entirety requires continual manual adjustments of the settings.

VGStudio Max can also export an "image stack" consisting of many two-dimensional grayscale image files corresponding to a set of uniformly spaced slices perpendicular to a chosen axis. Such a stack can then be viewed as a multilayered image in Photoshop or imported into other CT visualization software such as Osirix.[20] Using Photoshop one can make a manual tracing of the letters visible in the various layers, and by means of careful masking one can also generate a composite image from the most legible parts of different layers, simulating a nonplanar slice that bends with the inscribed surface. Experience shows that a combination of approaches is most productive, with Photoshop providing the most convenient means of reading the bulk of an inscription and preparing publishable images of large regions, while the CT visualization software provides greater control and clarity for the more difficult regions.

CT is the only means of reading letters on surfaces embedded within fragments.[21] It is also highly effective when one is dealing with exposed surfaces that are superficially corroded, since the letter outlines are generally much clearer in slices made deeper within the material. In general it is the technique on which we have relied most. For inscriptions on highly distorted exterior surfaces, however, and for a few fragments whose CT volumes have unsatisfactory clarity, the PTM technique is often preferable.

PTM, or Polynomial Texture Mapping, is currently the primary example of a class of techniques known as "Reflectance Transformation Imaging" or RTI.[22] This method involves photographing an object multiple times, each with a unique lighting direction, but keeping the relative position of the camera and subject fixed. This procedure samples the "reflectance function" of points on the surface of the object, specifically, how the

20 http://www.osirix-viewer.com.

21 The potential of tomographic imaging to reveal embedded inscriptions was first remarked by Wright, Bromley, & Mangou 1995, 542.

22 Malzbender, Gelb, & Wolters 2001; www.hpl.hp.com/research/ptm/ri.html; culturalheritageimaging.org/Technologies/RTI. The PTM data files of the Mechanism may be found at: http://www.hpl.hp.com/research/ptm/antikythera_mechanism/index.html.

color and intensity of those points vary with incoming illumination angle. Once acquired, low order mathematical models are fit to the reflectance functions independently for each pixel, allowing computer software to render the object surface at arbitrary lighting conditions in real time.

In addition, optical reflectance properties of the acquired surface can be transformed to provide renderings simulating material variations. For example, once the predominantly dull, diffuse reflectance of the Antikythera Mechanism fragments is acquired in this manner, it can be transformed to reflectance properties associated with shiny, specular surfaces such as obsidian or metal, allowing greatly improved perception of surface shape. Since these renderings can also be produced in real time, the user is free to vary lighting direction interactively to investigate specific regions of surface shape under these new material properties. This specific surface enhancement method is entitled *specular enhancement*. Other enhancement method variations can also be performed. For example, the technique of *diffuse gain* simply increases the second derivative, or curvature, of the reflectance function in lighting space, keeping the estimate of the surface normal (orientation) fixed. This causes surface appearance to be more sensitive to variations in lighting direction, a useful transformation not available in the physical world. Once again the investigator is free to vary lighting direction interactively in real time, greatly assisting in the perception of surface shape.

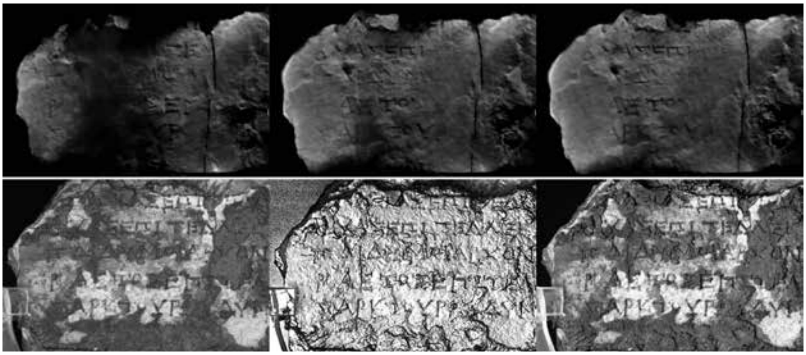


Figure 1.3: *Part of the Parapegma Inscription on Fragment C-1. Top, left to right, three CT "slices" at progressively lower levels relative to the surface of the inscribed plate. Bottom, left to right, PTM visualizations with simulated conventional illumination, specular enhancement, and diffuse gain (Images: Antikythera Mechanism Research Project)*

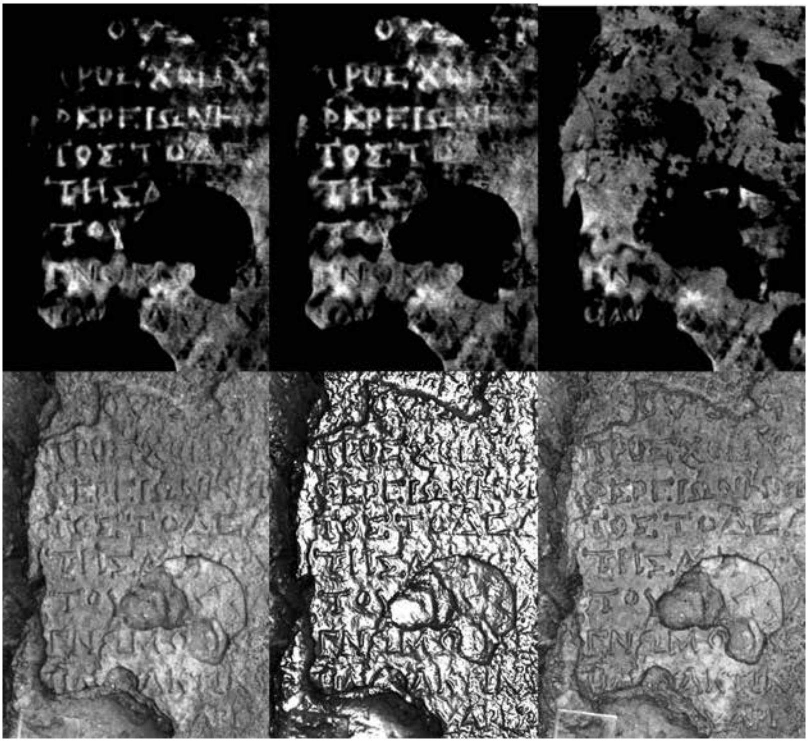


Figure 1.4: *Part of the offsets of the Back Cover Inscription on Fragment B-1. Top: CT "slices" as in Fig. 1.3 top. Bottom: PTM visualizations as in Fig. 1.3 bottom (Images: Antikythera Mechanism Research Project)*

Reading an inscription through PTM is an experience closer to that of traditional epigraphy than using CT, since it involves viewing a simulation of a three dimensional surface under light rather than ghostly outlines of letters in a slice through the material. Letter forms can look surprisingly different in CT, especially if the slice is near the level of the base of the grooves; markings arising from accidental causes can look deceptively like deliberate engraving; and parts of letters may be invisible at any slicing level on account of shallow engraving or surface corrosion. Prolonged practice and relying on more than one pair of eyes are the best protection against misreadings, especially those originating from wishful thinking.

1.3 Nomenclature of the Fragments

The letters A-G and numbers 1-75 used to identify the individual fragments are shown with the fragments in Fig. 1.1.[23] P. Rediadis and I. N. Svoronos introduced the designations A, B, C, and D for the four fragments known by early 1903, and assigned the numbers 1 and 2 to the two faces of each fragment.[24] Except for Fragment E, which was so designated in articles by M. T. Wright in 1997 and the early 2000s,[25] the remaining fragments did not receive a systematic nomenclature until 2005, when M. Zafeiropoulou, cataloguing in the Museum's bronzes storeroom the 79 currently identified fragments that were not on public display, extended the capital letter designations to F and G, and gave numbers from 1 through 75 to the remaining smaller fragments.[26] In the course of the 2005 AMRP data-gathering, the faces of Fragments E, F, G, and 1 through 75 were more or less arbitrarily assigned numbers 1 and 2 for the sake of standard reference. In the present series of papers we will employ the notation (e.g.) 43-2 to designate face 2 of fragment 43.

23 See also: http://www.antikythera-mechanism.gr/data/fragments.

24 Svoronos 1903a and 1903b.

25 Wright and Bromley 1997, Wright 2004, 9, and 2005, 10. Zafeiropoulou gave the same designation to E in 2005.

26 Zafeiropoulou 2012.

1.4 Layout of the Mechanism: Displays and Inscriptions

The identification of four distinct major inscriptions in addition to the various sets of dial scale inscriptions is chiefly due to Price.[27] Since the remains of these inscriptions exist in six of the "major" fragments (designated by letters) and more than twenty small fragments (designated by numbers), and range from just a few characters to extensive runs of partial lines of text, criteria are needed for identifying the inscriptions to which each belonged. These are:

i. Size of lettering and line spacing. As Price pointed out, the major inscriptions are each characterized by a fairly uniform average letter height (measured from the baseline to the top level of most letters) and line spacing (measured from baseline to baseline).[28] This criterion has broad applicability, even with very small fragments.
ii. Characteristic vocabulary. Three of the major inscriptions exhibit largely formulaic verbal patterns that repeat distinctive words and phrases, so that even one partially preserved characteristic word may suffice to identify a fragment's provenance.
iii. Matching of inscribed plate and offset fragments. Three of the major inscriptions survive partly through fragments of the original inscribed plates and partly through fragments of a layer of accretion that preserved mirror-reversed offsets of the lettering. Corresponding regions of plate and offset may be identified by even a few legible letters or parts of letters appearing (aside from mirror-reversal) in exactly the same configuration.[29] Since the lettering on one or the other of a pair of matched fragments may be damaged or obliterated, the existence of offsets can greatly enhance our ability to reconstitute the text. Additionally, some offsets preserve text where the original plate has not survived, or partly overlap two plate fragments, thus establishing their relative positions.
iv. Matching of fragments with photographs. Small fragments that were separated from the major fragments since their discovery in 1902 can sometimes be visually matched with parts of the major fragments in early photographs.

Referring to Figure 1.2, we outline of the Mechanism's displays and inscriptions as they are currently known:

27 Price 1974, 46-51.

28 Price 1974, 47-48.

29 Price 1974, 47, identified the match between Fragment 19 and offsets on Fragment A-2, and integrated the transcriptions from the two witnesses.

1. On the central square plate (Dial Plate) of the Mechanism's front face (*IAM* 3)

Most of the square plate was occupied by a large circular dial surrounded by two graduated scale rings. The Greek names of the signs of the zodiac were inscribed on the inner Zodiac Scale and the Greek names for Egyptian months on the outer Egyptian Calendar Scale, which was manually moveable to accommodate the gradual shift of the Egyptian calendar year relative to the seasons. Pointers revolving around the dial represented the motions around the zodiac of the Sun, the Moon, and the five planets known in antiquity, as well as the date in the Egyptian calendar year.[30] Short texts (single words and letters) were inscribed on the dial rings. The remains of these texts, collectively designated *Front Dial Inscriptions*, are all in Fragment C.

2. On two rectangular plates (Parapegma Plates) above and below the front Dial Plate (*IAM* 3)

These plates were inscribed with the *Parapegma Inscription*, comprising a list of first and last visibilities of stars, which linked to index letters on the Zodiac Scale. During or after the shipwreck they became displaced and ended up lodged between the Front Cover Plate and the Mechanism's front face. The remains of the Parapegma Inscription are in Fragment C and several small fragments (9, 20, 22, and 28).

3. On the dials of the Mechanism's back face (Back Plate) (*IAM* 4)

The largest features of the back face were two large dials, each consisting of a spiral groove, which was originally tracked by the end of a variable-radius pointer-follower. The spiral-shaped strip of plate running along the exterior of the successive turns of the groove was a scale engraved with radial lines dividing it into cells. The upper spiral (Metonic Dial) represented a 19 year Metonic lunisolar cycle of 235 lunar months, and its cells were inscribed with the local names of months and the numbers of years within the cycle. Immediately inside the innermost turn of the groove, numbers were inscribed representing a repeating cycle of 29-day and 30-day lunar months. Within the circular space inside the spiral, a small circular dial (Games Dial) had a pointer revolving once every four years; this dial was inscribed on the inside with the ordinal numbers of the cycle's years, and on the outside with the names of Greek athletic competitions that were held at two-year and four-year intervals. Inside the Metonic Dial to the left, it is conjectured that there was another subsidiary dial (Callippic Dial), showing the 76 years of the Callippic calendar.

The lower spiral dial (Saros Dial) represented a 223 lunar month Saros eclipse cycle.

30 The inscriptional evidence for planetary pointers is discussed in *IAM* 5 and 6.

Some of its cells at five-month or six-month intervals were inscribed with highly abbreviated inscriptions ("glyphs") indicating the possibility that a solar eclipse or a lunar eclipse (or both) could occur at the new or full Moon during the current month. There was also a small circular dial (Exeligmos Dial) in the space inside the spiral, which showed the triple Saros or Exeligmos cycle, with a pointer revolving once every 669 lunar months. This dial was inscribed with numbers involved in the adjustment of the time of day predicted (on the glyphs) for occurrence of the eclipse.

The inscriptions of all the foregoing dial scales are collectively designated *Back Dial Inscriptions*. Those of the upper dials are preserved in Fragment B, the remainder in Fragments A, E, F, 24, and 25.

4. Around the dials of the Back Plate (*IAM* 4)

An extended text (the *Back Plate Inscription*, BPI) was inscribed in the spaces of the back face surrounding the two spiral dials; remains of it are in Fragments A, E, F, 24, and 25. It gives further information about groups of eclipses, referred to by index letters in the glyphs.

5. On the Front Cover Plate (*IAM* 6)

A long text, the *Front Cover Inscription* (FCI), was inscribed on the Front Cover Plate. Its remains, which were attached to Fragment C as it was discovered in 1902, now comprise Fragment G and numerous small fragments (21, 23, 26, 27, 29, 37–44, 49, 54-56, and 60). The text describes the synodic cycles of motion of the five planets relative to the Sun and around the zodiac.

6. On the Back Cover Plate (*IAM* 5)

A long text, the *Back Cover Inscription* (BCI), was inscribed on the back cover plate. It comprises a description of the dials and other features of the Mechanism's front and back faces. Its remains are in Fragments A, B, E, 19, and 67.

7. On interior components and unplaced small fragments

A few isolated letters or numerals are found on components of the Mechanism that would not normally have been exposed to view. These were likely part-identifiers for the benefit of the builder or operator of the Mechanism.[31] These include the following:

31 Price 1974, 20.

On A-2, near the top, an offset letter previously read as H (eta), but probably to be viewed sideways and read as Ξ (xi, numerical value 60) in the form of that letter that has a vertical stroke crossing the three horizontals (Ɨ).[32]

On C-2, near the center of the cylindrical cap feature and again on the lunar phase apparatus about halfway between the remains of the contrate and of the Moon ball, T (tau, numerical value 300).[33]

Inside Fragment D, inscribed on both the single gear preserved in this fragment and on a disk riveted to this gear, ME (mu ..., numerical value 45).[34]

Additionally, there remain a few tiny fragments in the range 45-75 bearing bits of inscription whose provenance has not been identified. These are not included in the present series of papers.

The inscriptions served several distinct functions. The dial inscriptions gave the positions of the pointers immediate meaning, in terms of astronomy and systems of time-reckoning. The pointer positions predicted recurring astronomical and terrestrial events, e.g. eclipses, planetary positions and athletic competitions. Back Plate Inscription and Parapegma Inscription augment the information on astronomical phenomena predicted by the dial displays. The Front Cover Inscription is a more general description of the behavior of the planets displayed by pointers on the front dial, while the Back Cover Inscription helps the viewer to identify the meaning of the displays on both faces of the Mechanism.

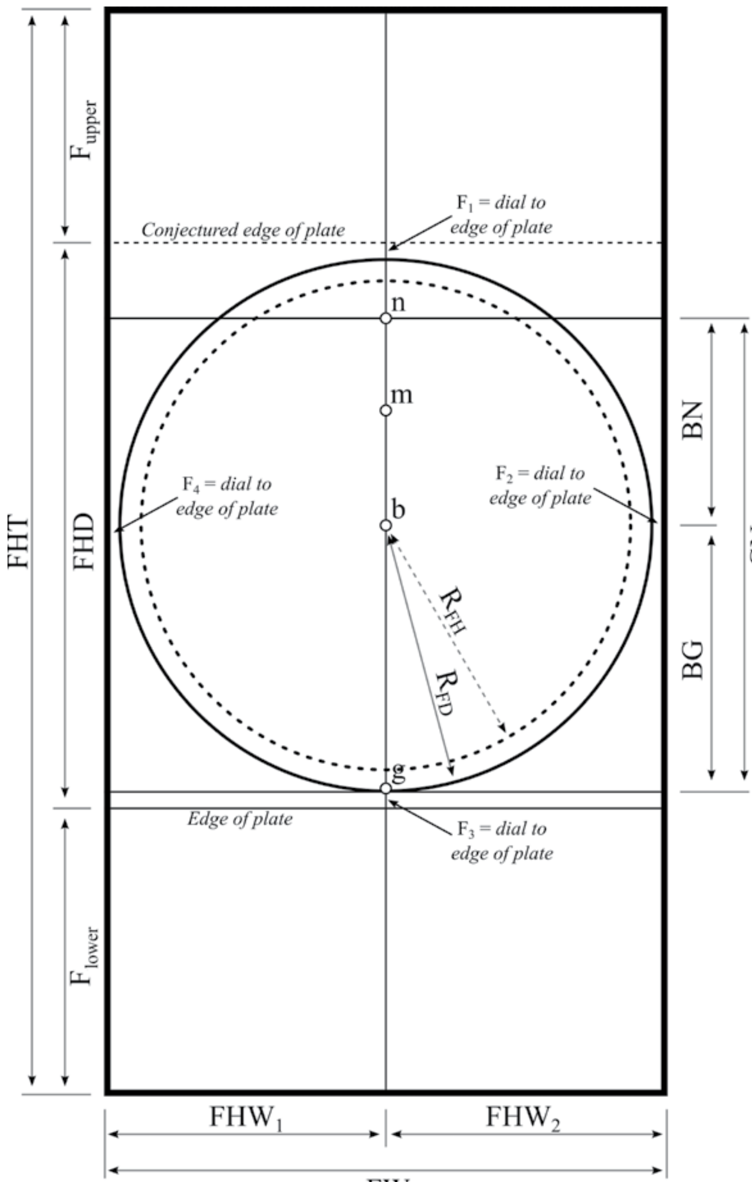
32 The letter was described, fairly precisely, by Rediadis in Svoronos 1903a, 45 (= Svoronos 1903b, 45). Identified as eta by Price 1974, 20.

33 Rediadis in Svoronos 1903a, 47 (= Svoronos 1903b, 46); Wright 2006, 326 figure 8.

34 Freeth & Jones 2012, section 3.6.2.

1.5 The Dimensions of the Antikythera Mechanism

To determine the space available for inscriptions, we combine various measurements to estimate the dimensions of the front and back faces of Mechanism. The nomenclature of the features and distances is given in Fig. 1.5.



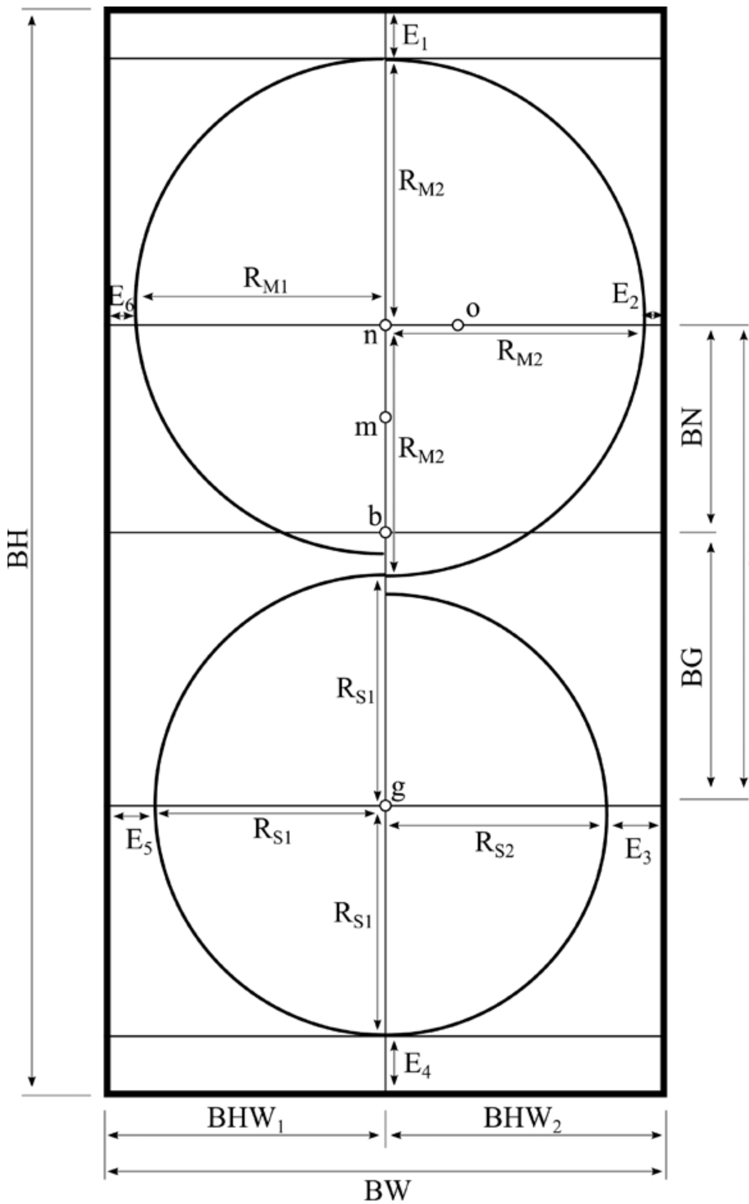


Figure 1.5: *Diagrams for determining the dimensions of the Mechanism's front and back plates*

(1) BG: The distance between the main front dial pointer axis b and the lower back (Saros) dial pointer axis g

Measurement of g to b is possible visually on the rear of fragment A using a calibrated digital photographic image, 02 A-2 4000 (the nomenclature is a series number followed by the fragment and face designation followed by the image's linear pixel size, i.e. 4000 indicates a 4000x4000 pixel image) . The result for BG is 79.5 mm, which agrees exactly with measurement on Price's (1974) Fig. 29, although it is slightly different from the 78 mm he quotes on p. 15, near the foot of the right-hand column. We adopt BG = 79.5 mm.

(2) BN: The distance between the main front dial pointer axis b and the upper back (Metonic) dial pointer axis n

Measurement of b to gear train axis m is possible visually on images of the rear of fragment A as above. The result is 47 mm. The distance between axes m and n (missing from fragment A) can be estimated by the radii of gears from the table of gear sizes in Freeth *et al.* 2006, Supplementary Information. Gear m2 has radius 4 mm, and we assume that the conjectured gear n1 has the same radius (14 mm) as the gear f1 which has the same tooth count. Thus total distance b to n is 47 + 4 + 14 = 65 mm, which agrees exactly with measurement on Price 1974, Fig. 29. We adopt BN = 65 mm.

(3) GN: The distance between the upper back (Metonic) dial pointer axis n and the lower back (Saros) dial pointer axis g

A direct estimate of the inter-axial distance GN is given by adding BG + BN = 79.5 + 65 = 144.5 mm, with an estimated error of ±2 mm. An independent measurement of 143.4 mm has been given by Anastasiou, Seiradakis, Carman, & Efstathiou 2014, although they adopt 150.3 mm for manufacturing a physical model.

We can also make an alternative estimate via o-n and o-g by noting that axes o and n are at the same level vertically. Their distance apart can be estimated on a radiograph (013 B 150 keV; the nomenclature is a series number followed by the fragment designation and the energy of the X-ray source), and setting a scale by assuming the central radii of the Metonic dial slots (see below). Setting the centre of the dial by the circular hole through which the axis passes, the distance o-n is 24 ± 0.5 mm. The measured inner and outer tooth radii of gear o1 (from Freeth *et al*. 2006, Supplementary Information) are 12.2 mm and 13.3 mm respectively, while we expect the corresponding radii of the missing n1 to be 12.5 mm and 13.1 mm by analogy with the existing gear i2 which has the same number (53) of teeth. Adding one inner to one outer radius to mesh gives o-n as 25.5 ± 0.3 mm.

So a reasonable estimate for o-n is 25.0 ± 1 mm. For o-g, a 3D surface model of A2, made from photos by photogrammetry, and calibrated according to radius of e3 = 52.4 mm, gives a distance between the visible centres of g and o as 149.6 mm. But there is also a front-to-back distance between the planes containing the visible centres of g and o, which is estimated (roughly) to be about 14 mm, and this would correct the true in-plane measurement of o-g to $\sqrt{149.6^2-14^2}$ = 148.9 mm. Combining with o-n gives GN = $\sqrt{148.9^2-25^2}$ = 146.8 mm.
We adopt 145.5 ± 2 mm for GN.

(4) Radius of the Metonic dial slots

The structure of the back dials as spiral slots constructed from semicircles was first identified by Wright 2004, and further investigated by Anastasiou, Seiradakis, Carman, & Efstathiou 2014. Price 1974, 15 gives measurements of some of the slots. We have fitted circles to the fragment B visual image 10 B2 4000 and also to an X-ray image (13 B 1500kV). Least-squares fitted circles to the edges of the right-hand slots (as viewed from the back, and requiring that they share a common centre) give the results in the second column of Table 1, with an estimated error of ±1 mm. Estimate can also be made, to about ±2 mm, from Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 9, and (for comparison with previous work) by fitting circles to the reconstruction of the dial in Freeth, Jones, Steele, & Bitsakis 2008, Fig. 15. We use the nomenclature R_{M1}, R_{M3}, R_{M5}, R_{M7}, R_{M9} for the left-hand semicircles' radii (in decreasing size order) and R_{M2}, R_{M4}, R_{M6}, R_{M8}, R_{M10} for the right-hand semicircles.

Our fitting of circles shows that the center of the *right-hand* semi-circle is indeed the axis n, in agreement with Anastasiou, Seiradakis, Carman, & Efstathiou 2014, who call this the "pointer axis."

Table 1.1: *Estimates of the right-hand Metonic Dial slot radii in mm (to center of slot)*

Slot	*Measured radius*	*Adopted radius*
R_{M2}	74	73
R_{M4}	65	65
R_{M6}	58	58
R_{M8}	51	51
R_{M10}	43.3	43

Table 1.2: *Comparison of estimates of the largest left-hand Metonic Dial slot radius in mm*

Slot R_{M2}	This paper: from visual image	Price 1974	This paper: measured from reconstruction in Freeth, Jones, Steele, & Bitsakis 2008, Fig. 15	This paper: from X-ray image	From Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 9
Centre	75	74			
Outer side			73	74.9	76.6
Inner side				73.5	75.5

Our Table 1.1 X-ray measurements of the slot radii imply a regular spacing of 7.5 ± 0.5 mm. This estimate excludes the measured R_{M2}, which appears anomalously large for an assumed regularity of spacing, and—as there may be some mechanical distortion—we have decided to correct this R_{M2} downwards by 1 mm. We adopt R_{M2} = 73 ± 1.5 mm as the central radius of the largest right-hand Metonic slot. The central radius of the largest *left-hand* slot is therefore expected to be 7.5/2 = 3.75 mm less than that of the right-hand slot, giving R_{M1} = 69 ± 1.5 mm.

To summarize, we adopt R_{M1} = 69 ± 1.5 mm, R_{M2} = 73 ± 1.5 mm as the central radii of the largest part of Metonic Dial slot. Slot widths are approximately 1.5 mm. A half-slot width *s* (0.75 mm) must be added to each central slot radius to convert to the outer slot radius.

(5) Radius of the Saros dial slots

This is rather more problematic than for the Metonic dial, since in the visual images the scales appear somewhat distorted (presumably through damage), as was noted by Price 1984, 15, and some distortion is also visible in the CT. We confirm that the axis g is the centre of the semi-circles on the *left-hand* side of the dial (as viewed from the back), as also found by Anastasiou, Seiradakis, Carman, & Efstathiou 2014. We adopt the nomenclature R_{S1}, R_{S3}, R_{S5}, R_{S7} for the left-hand semicircles' radii (in decreasing size order) and R_{S2}, R_{S4}, R_{S6}, R_{S8} for the right-hand semicircles.

Using a stacked CT X-ray image, we have least-squares fitted circles to edges of the slots on the right-hand side of the dial, requiring they share a common center, to an accuracy of about ±2 mm. The results for the largest right-hand slot R_{S2} are given in Table 1.3. Price does not give an estimate of the outer slot, although his inner and outer radii for the sides of the third slot inwards S6 at 52.3 mm and 54.4 mm agree well, within expected errors, with our measurements of 51.9 mm and 53.4 mm.

Table 1.3: *Estimates of the largest right-hand Saros Slot radius in mm*

Slot R_{S2}	This paper: from X-ray image	From Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 10
Outer side	69.8	70.9-72.8
Inner side	68.1	69.7

Our X-ray measurements give the following radii for the outer and inner radii of the right-hand side slots: 69.8, 68.1 for S2; 61.5, 59.9 for S4; 53.4, 51.9 for S6; thus giving centre slot radii of R_{S2} = 69, R_{S4} = 60.7, R_{S6} = 52.7, and an average inter-slot distance of 8.2 mm. The corresponding value from Anastasiou, Seiradakis, Carman, & Efstathiou 2014, Fig. 10 is rather uncertain, but of order 9-10 mm. We adopt 8.2 ± 0.5 mm. The radius of the largest *left-hand* slot is therefore expected to be 8.2/2 = 4.1 mm more than that of the right-hand slot, giving R_{S1} =73 ± 2 mm. Anastasiou's value would be around 76 mm, and a measurement from the Figure 25 reconstruction of Freeth, Jones, Steele, & Bitsakis 2008, Fig. 25 gives 71 mm.

To summarise, we adopt R_{S1} =73 ± 2 mm and R_{S2} = 69 ± 2 mm as the central radii of the largest part of the Saros Dial slot. Slot widths are approximately 1.5 mm. A half-slot width *s* (0.75 mm) must be added to each central slot radius to convert to the outer slot radius.

(6) Other Back Plate distances

Measurement on both visual and CT images yields E3 = 15.5 mm as the distance from the outer slot center to the right-hand edge of the back plate. The plate's right-hand-side "half width" $BHW_2 = R_{S2} + s + E3 = 69 + 0.75 + 15.5 = 85$ mm. On the CT the distance from the outer spiral slot edge to bottom of plate is E4 = 12 mm.

(7) Front Dial outer radius

We have used CT images of fragment C, which is the lower left-hand corner (as viewed from the front) of the front dial, to least-squares fit circles to the dial annuli and the ring of 365 holes. The radius of the ring of holes is R_{FH} = 74.0 mm, with an error of ±3 mm estimated from experimenting with fitting the ring in segments. The measured distance between ring of holes and the outer edge of the dial is 7 mm. This gives an estimated radius for the dial of R_{FD} = 81 ± 3 mm, which we adopt. The fitted outer radius of the front dial is 80.5, in excellent agreement. Price estimates 77.2 mm. It is also possible from the CT to estimate the (quite small) distance F_3 between the edge of the outer dial and the bottom edge of the front dial plate, giving F_3 = 1.5 mm.

(8) Back and Front Plate Widths and Heights

We adopt the nomenclature BW, BH for the Back Plate's width and height, FW for the Front Plate's width, FHD for the height of the front Dial Plate containing the dial, and FHT for the total height of the complete Front Plate assembly comprising the Dial Plate and the two Parapegma Plates. If we assume that the plates are rectangular, then:

$$
\begin{aligned}
BW &= BHW_1 + BHW_2 \\
&= E_5 + R_{S1} + s + R_{S2} + s + E_3 \\
&= E_6 + R_{M1} + s + R_{M2} + s + E_2 \\
FW &= FHW_1 + FHW_2 \\
&= F_4 + 2\,R_{FD} + F_2 \\
BH &= E_1 + R_{M2} + s + GN + R_{S1} + s + E_4 \\
FHD &= F_1 + 2\,R_{FD} + F_3 \\
FHT &= F_{upper} + FHD + F_{lower}
\end{aligned}
$$

where F_{upper} and F_{lower} are the heights of the spaces available for the Parapegma Plates above and below the Dial Plate. Filling in the adopted values gives:

$$
\begin{aligned}
BW &= E_5 + 73 + 0.75 + 69 + 0.75 + E_2 \\
&= E_6 + 69 + 0.75 + 73 + 0.75 + 15.5 \\
FW &= FHW_1 + FHW_2 \\
&= F_4 + 162 + F_2 \\
BH &= E_1 + 73 + 0.75 + 144.5 + 73 + 0.75 + 12 \\
&= 304 + E_1 \\
FHD &= F_1 + 162 + 1.5 \\
&= F_1 + 163.5 \\
FHT &= F_{upper} + FHD + F_{lower}
\end{aligned}
$$

The difference between the outer radii of the upper and lower spirals on the back poses the question of whether the vertical line through the pointer axes was *centred* front and back. On the assumption that it was, then $BHW_1 = BHW_2$ and:

$$
\begin{aligned}
BW/2 &= E_6 + R_{M1} + s \\
&= R_{M2} + s + E_2
\end{aligned}
$$

giving

$$E_6 = 4 + E_2$$

and

$$
\begin{aligned}
BW &= 147.5 + 2\,E_2 \\
BW/2 &= E_5 + R_{S1} + s \\
&= R_{S2} + s + E_3
\end{aligned}
$$

giving

$E_5 \quad = E_3 - 4$

$\quad\quad = 11.5$

and

$BW \quad = 138 + 1.5 + 2\,E_3$

$\quad\quad = 170.5$

Combining this with the previous result gives

$E_2 \quad = 11.5$

$E_6 \quad = 15.5$

Rounding, we have BW = 171, with an error of ±3 mm. If centred, then $F_2 = F_4$, so

$FW \quad = 162 + 2\,F_2$

If, and only if, front and back are of equal width, then $170.5 = 162 + 2F_2$ and $F_2 = F_4 = 4$. F_2 and F_4 are rather larger than the measured value of $F_3 = 1.5$ mm, the distance of the bottom of the front dial from the plate edge, but there is no reason (other than neatness) that the top and side spacings should be the same. Hence reasonable estimates for FW lie in the range to 167 to 174 mm, or perhaps 165 to 176 mm when all estimation errors are taken fully into account, with a preferred value around 170.5 mm.

If, and only if, the heights, top and bottom about the axis b, of the back dial are the same as the front dial, then

$BN + R_{M2} + s + E_1 \quad = R_{FD} + F_1 + F_{upper}$

$BG + R_{S1} + s + E_4 \quad = R_{FD} + F_3 + F_{lower}$

Assuming initially that $F_1 = F_3 = 1.5$ mm, then FHD = 165. Hence

$BN + R_{M2} + s + E_1 \quad = 65 + 73 + 0.75 + E_1$

$\quad\quad = 81 + 1.5 + F_{upper}$

so that

$F_{upper} \quad = 56 + E_1$ mm

Again,

$BG + R_{S1} + s + E_4 \quad = 79.5 + 73 + 0.75 + 12$

$\quad\quad = 81 + 1.5 + F_{lower}$

so that

$F_{lower} \quad = 83$ mm.

The minimum value of E_1 can be estimated as the width of the scale (7.5 mm, see discussion above of the Metonic dial slots) plus, say, 1.5 mm (cf. F_3), giving E_{1min} = 9 mm. If E_1 is symmetric with E_4, then E_1= 12 mm. The corresponding values are BH = FHT = 313 mm to 316 mm, and F_{upper} = 65 mm to 68 mm, with estimated errors around ±3 mm. There is no obvious constraint on an upper value for E_1, so these values could be larger.

(9) The "best estimates"

Front and Back plate heights: FHT = BH = 313 mm to 316 mm

Plate widths: FW = BW = 171 mm
Parapegma plates: height available for top plate 65 mm to 68 mm;
height available for lower plate 83 mm; width 171 mm.

Compounded measurement errors on these numerical values are estimated to be of order ±3 mm. If the condition that front and back plates are of identical size were relaxed, then the space available for the Parapegma plates could change; in particular the space could be slightly narrower, but not below 162 mm.

(10) Did the slots of the spiral dials intersect?

The central radius of the largest slot of the Metonic dial is estimated as 73 mm, and the central radius of the largest slot of the Saros dial is also estimated as 73 mm, so their sum is 146 ± 3 mm. Our adopted distance between their axes is estimated as 145.5 ±2 mm. Within the errors, the slots would indeed intersect—although since the slot width is of order 1.5 mm, the errors could allow that their ends did not quite meet. The dial plate might have been slightly mechanically stronger if the slots were not continuous, but there could have been an advantage for a continuous slot in that that driving the pointer-followers a bit too far in the forward-time direction would not stress the mechanism.

Freeth, Jones, Steele, & Bitsakis 2008, Fig. 2 have an interaxial distance ng of 150 mm (cf. our value 144.5), with the sum of the radii of the Metonic and Saros slots as 73 + 71 = 144 mm (cf. our value 146), allowing a distance of 6 mm for a scale between the (un-connected) slots. Their construction is neat, but the required sizes—particularly the interaxial distance—seem to stretch the error levels on our adopted measurements rather far.

1.6 Conventions for the editions

For most of the Mechanism's inscriptions, the editions in this series of papers are the first to employ the full Leiden conventions standard for epigraphical texts[35] and to provide detailed epigraphical apparatus. We use the following notations:

[αβγ]	lost text, editorially restored.[36]
α̣β̣γ̣	unclear letter traces, ambiguous outside their context.
. .	unclear letter traces, insufficient for restoration.
ABΓ	clear but unconstruable letters.
nn	lost numerals.
v	*vacat* (vacant space).
- 14 -	estimated space for 14 lost letters.
— — —	broken top or bottom.

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Enquiries via www.antikytheramechanism.gr/contact/.

35 Van Groningen 1932.

36 In the translations, partially preserved words are bracketed entire if the surviving letters are insufficient to determine the word, and left entirely unbracketed if restorations are certain.

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