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**Hero of Alexandria's *Automata*. A Critical
Edition and Translation, Including a
Commentary on BOOK ONE**

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Submitted in fulfilment of the requirements for the
degree of Doctor of Philosophy (Ph.D.)

School of Humanities
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November 2019

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ABSTRACT

This thesis is a critical edition, with introduction, translation and partial commentary, of the *Automata*, a two-book mechanical treatise written by Hero of Alexandria (first century CE). It provides the first commentary on BOOK ONE, dealing with the construction of a mobile, as opposed to a stationary, automaton.

The preface summarises the significance, aims and limitations of the work. The opening section gives a summary of some of the conventions and abbreviations used in the thesis, and is followed by a list of figures.

The introduction provides a context for an informed reading of the text. It consists of six parts. Part One discusses the ‘Heronian question’, with particular attention to the chronology of the *Automata* and the *Pneumatica*. Part Two evaluates previous editions and translations, and summarises the main novelties of this study. Part Three assesses the manuscript tradition, including a stemmatic analysis of a large number of manuscripts. Part Four mainly discusses the various forms of the title of the treatise, which is reconstructed as *Περὶ αὐτομάτων* (*On Automata*). Greater uncertainty surrounds the heading of BOOK TWO, *Περὶ στατῶν αὐτομάτων* (*On Stationary Automata*), which may have been derived from Hero’s source, Philo of Byzantium (third-century BCE). Part Five focuses on the work itself. It starts with an overview of the structure of the text, with remarks on previous editorial practices. This is followed by a critical description of the contents of the treatise and by a discussion of the historical, literary and cultural background. This, in turn, allows for consideration of the performative context of Hero’s automata. Attention is then paid to the purpose and intended audience of the treatise, followed by an exploration of Hero’s relationship with his sources. A stylistic comparison with the *Pneumatica* sheds new light on Hero’s degree of originality, removing suspicions of interpolation. Finally, discussion turns to the status of the text. Internal inconsistencies are best explained as the result of incomplete authorial editing. Part Six addresses the principles of the edition.

The text, apparatus criticus and translation form the centre of the thesis. To maximise readability, the layout of the English translation mirrors the layout of the Greek text. The elucidation of the manuscript sigla and abbreviations used in the apparatus criticus precedes the text.

The commentary is mainly philological and text-critical in nature. However, it also addresses stylistic, interpretive and reconstructive issues, without failing to consider the oldest manuscript diagrams.

Following the commentary are six appendixes: (1) a concordance of editions; (2) *addenda et corrigenda* to Schmidt’s edition; (3) three *stemmata codicum*; (4) illustrations; (5) a review of Masià (2015); (6) an index of technical terms. Appendix (4) includes manuscript diagrams and reconstruction drawings of the mobile automaton. The thesis closes with a bibliography.

PREFACE

The *Automata*, our only extant treatise on the design and construction of ancient automata, was probably written sometime between the second half of the first century and the beginning of the second century CE by Hero of Alexandria, one of the most well-known technical and mathematical writers of antiquity. The treatise, which in all likelihood was published (posthumously?) in an incompletely revised form, is divided into two books, each devoted to a different type of automaton, one mobile (ῥπαγον) and the other stationary (στατόν). We know little about Hero's sources, except that he drew directly on a lost treatise by the third-century BCE mechanical writer Philo of Byzantium for the second part of his work. In fact, it has been suggested that the greater portion of BOOK TWO repeats *verbatim* Philo's earlier text,¹ and there are indications, including linguistic and stylistic differences between the two books, which tend to confirm this suggestion. Apart from this, a stylistic comparison with the *Pneumatica*, a treatise on pneumatic devices, suggests that Hero made eclectic use of multiple sources, often improving pre-existing technology.

The *Automata* is of particular importance for our understanding of both the history of science and technology and Hellenistic and Imperial entertainment culture. Thus far, scholars have tended to focus on particular aspects of the work, such as its continuities and discontinuities with mathematical prose,² the mechanisms of movement of the mobile automaton,³ or the theatrical relevance of the stationary model.⁴ However, since the appearance of Schmidt's standard edition in 1899 (with notes, but without a commentary), very little attention has been paid to text-critical problems,⁵ and the sole English translation of the treatise, published by Murphy in 1995, is neither widely available nor unproblematic.

¹ Schöne (1891: 77).

² Cambiano (2011).

³ McCourt (2012). On the relationship between the mobile automaton and construction machinery, artillery and water-lifting machines, see Keenan-Jones–Ruffell–McGookin (2016).

⁴ Marshall (2003) and Beacham (2013).

⁵ The most notable exception is the exchange on interpolations between Olivieri (1901) and Schmidt (1903).

This thesis has been undertaken as the philological component of a larger research project, ‘Hero of Alexandria and his theatrical automata’, headed by Professor Isabel Ruffell (School of Humanities, Classics) in collaboration with Dr. Euan McGookin (School of Engineering). The purpose of this project was to investigate the historical, technical and theatrical context of the treatise, the practical and technical viability of the automata (in particular, of the mobile type), and their influence on developments in Renaissance automata and robotics. As part of the project, the present thesis aims to provide a new critical edition of the text, accompanied by apparatus criticus, an English translation, a detailed introduction and a full-scale commentary on BOOK ONE. In particular, it sets out to offer a fresh interpretation of the text, giving special attention to the following aspects: (1) the language and style of Hero; (2) the nature and (philological) status of the text; (3) the manuscript tradition of the text; (4) the situation of the work within the ancient tradition of automata-making; (5) whether and how Hero’s devices functioned; (6) Hero’s degree of originality.

As with any study, this work has limitations. First, although the edition is based on the collation of a larger number of manuscripts than the previous edition, it has not been possible to access all manuscripts nor to collate all the available manuscripts fully (see further Introduction, §§3.1-2). Because of this, and in the absence of an apparatus fontium,⁶ no attempt has been made to use sigla for the consensus of all complete manuscripts or between groups of manuscripts. Second, the introduction does not include full discussion of the instructional mode in the treatise both because this requires a separate and detailed treatment and because there is no commentary on BOOK TWO.⁷ Third, the thesis does not purport to offer a technological history of the automata or to investigate the text in direct relation to broader technological discourses. Technical and technological issues are addressed in a number of places but do not constitute the main approach of the thesis.

⁶ This will be added at the stage of revising the thesis for publication. The need for an apparatus fontium depends on the fact that some manuscripts are fragmentary.

⁷ Reasons of word-count and time prevented me from writing a commentary on BOOK TWO. This is of course not to say that the text of BOOK TWO has not been studied. See my remarks in Introduction, §6.1. I intend to produce a full commentary when preparing the thesis for publication.

ACKNOWLEDGMENTS

I would have never embarked on the study of Greek science were it not for my former supervisors, Professor Camillo Neri and Professor Valentina Garulli. My Master's dissertation, which I defended at the University of Bologna, Italy, in November 2013, started out with the intention of investigating the whole of book fourteen of the *Palatine Anthology*, thus covering three different epigrammatic genres – arithmetic problems, riddles and oracles. Because of time constraints, and because of the overly ambitious scope of the project, it was agreed that I would confine my study to arithmetic epigram, a choice made all the more apropos by the structure of the book itself. All of a sudden, then, I found myself developing a particular interest in the playful side of Greek mathematics. This provided a springboard for expanding my interests and venturing into the study of Greek mechanics. I thank my former supervisors for enabling me to take the leap.

I am very grateful to The Leverhulme Trust, who funded the research project 'Hero and his theatrical automata' during the years 2014–2017 and without whose support this thesis could not have been undertaken.

I owe a very special debt to Professor Isabel Ruffell, who supervised my doctoral work and patiently advised on every aspect of the thesis. Without her constant encouragement, critical insight and careful guidance, this study could not have been completed in its present form. Her style of mentoring taught me many precious lessons. It challenged me to push my intellectual boundaries, clarify my arguments, and strive for logical coherence. Most of all, perhaps, it empowered me to trust my intuitions. I am also extremely thankful to my second supervisor, Professor Costas Panayotakis. He taught me the real meaning of rigor, precision and accuracy. I am very much indebted to him for showing me how to make the apparatus criticus come to speak to the reader. The presentation of the material in the section on 'Conventions and abbreviations' owes much to his edition of the fragments of the Roman mimographer Decimus Laberius (Panayotakis 2010).

I also wish to thank Dr. Duncan Keenan-Jones, who has participated in the experimental strand of the project and reconstructed Hero's mobile

automaton. He kindly allowed me to access and use the reconstruction drawings of the automaton. **Figs. 3, 24b and 26b** are based on his work. A similar debt of gratitude goes to Riccardo Ravecca, friend and architect, who explained to me the basic conventions of architectural drawing and who drew some of the more challenging illustrations appended in the thesis (**Figs. 2 and 6b**).

Parts of the thesis were delivered at conferences and seminars in Glasgow, Madrid, St. Andrews and Canterbury. I am grateful for comments and suggestions received on these occasions.

I wish to express my thanks to the following libraries that provided me with reproductions of manuscripts: Biblioteca Angelica, Rome; Biblioteca Nazionale Centrale, Florence; Biblioteca Nacional de España, Madrid; Biblioteca Nazionale Marciana, Venice; Biblioteca Nazionale Universitaria di Torino, Turin; Bodleian Library, Oxford; Det Kongelige Bibliotek, Copenhagen; Herzog August Bibliothek, Wolfenbüttel; Österreichische Nationalbibliothek, Vienna; Real Biblioteca del Monasterio de El Escorial, San Lorenzo de El Escorial; Universiteitsbibliotheek van Amsterdam, Amsterdam; Veneranda Biblioteca Ambrosiana, Milan. I am also particularly grateful to the librarians of the Universiteitsbibliotheek Leiden and the Bibliothèque National de France, Paris, for granting me access to their manuscript collections.

Mr. Christopher Ashill, from the Joint Library of the Institute of Classical Studies and the Hellenic and Roman Societies, has been kind enough to send me scans of Vicente Bécara's *Diccionario de terminología gramatical griega*, Salamanca 1985, and I gratefully acknowledge his help.

I extend my warmest thanks to Dr. Natalia Tsoumpra, Dr. Elena Giusti and Dr. Arianna Gullo, for their friendship and support, and to all my other friends, both in Glasgow and elsewhere, who endured my anxieties and frustrations.

My last words of gratitude go to my partner Enrico and my mother Donatella, for without them I would have never made it this far. It is to them that I dedicate this thesis.

CAVEAT TO THE READER

At the stage of revising the thesis I obtained copies not only of the most recent edition of Hero's *Metrica* (Acerbi-Vitrac 2014) but also of two less frequently cited studies which deal with, or touch upon, the delicate and complex question of Hero's date (Reinhardt 1930; Sakalis 1972). I have been unable to incorporate these studies into the present thesis. It is worth noting that, while Acerbi-Vitrac (2014: 16-22) offer a valuable discussion of the most important pieces of evidence which are generally used for dating Hero, they are overly pessimistic about the possibility of establishing a fairly secure chronology for the author. The study by Sakalis (1972: 158-60), primarily on linguistic grounds, makes Hero contemporary with Nero, thus lending further precision to Reinhardt's (1930) previous linguistic and stylistic analysis (first century BCE/first century CE). I therefore encourage the reader to consider the opening section of the Introduction only as a preliminary foray into a much-needed reassessment of the *status quaestionis* on the chronology of Hero and his works. For discussion of the problems associated with Masià's (2015) argument that the eclipse of *Dioptr.* ch. 35 cannot be used for dating Hero, see **Appendix 5**.

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CONVENTIONS AND ABBREVIATIONS

1. ANCIENT AUTHORS

Abbreviations of ancient authors and their works follow the conventions of Liddel's and Scott's *A Greek English Lexicon*, revised and augmented by Jones (henceforth LSJ), of Glare's *Revised Supplement to LSJ* (henceforth LSJ, *Supplement*) and of the *Oxford Latin Dictionary* (henceforth OLD), with the following additions:

Anon. <i>Vit. Aesch.</i>	Anonymus <i>Vitae Aeschyli</i>
Eust. Antioch. <i>Engastr.</i>	Eustathius Antiochensis, <i>De Engastrimytho contra Origenem</i>
Gal. <i>Al. Fac.</i>	Galenus, <i>De alimentorum facultatibus</i>
—— <i>Foet. Form.</i>	Id., <i>De foetuum formatione libellus</i>
—— <i>Meth. Med.</i>	Id., <i>De methodo medendi libri quattuordecim</i>
—— <i>San. Tu.</i>	Id., <i>De sanitate tuenda</i>
Georg. Torn. <i>Or. Georg. Xiph.</i>	Georgius Tornices, <i>Orationes in honorem Georgii Xiphilini</i>
Hero, <i>Mech. Frag.</i>	Hero Alexandrinus, <i>Mechanicorum fragmenta</i>
Hero Byz.	Hero Byzantinus, <i>De strategematibus</i>
Jos. Genes.	Josephus Genesius, <i>Regum libri quattuor</i>
Marc. Diac. <i>Vit. Porph.</i>	Marcus Diaconus, <i>Vita Porphyrii</i>
Max. Conf. <i>Amb.</i>	Maximus Confessor, <i>Ambigua ad Joannem</i>
<i>Paraphr. rec. in Lycophr.</i>	<i>Paraphrasis recentior in Lycophronem</i>

Ph. <i>Parasc.</i>	Philo Byzantinus, <i>Parasceuastica et poliorcetica</i> ¹
Plu. <i>Aet. Rom.</i>	Plutarchus, <i>Aetia Romana et Graeca</i>
—— <i>Cur.</i>	Id., <i>De curiositate</i>
—— <i>Ser. Num.</i>	Id., <i>De sera numinis vindicta</i>
—— <i>Praec. Ger. Reip.</i>	Id., <i>Praecepta gerendae reipublicae</i>
Ps.-Nonnus, <i>Comm. in Greg. Naz. Serm.</i>	Pseudo-Nonnus, <i>In quattuor orationes Gregorii Nazianzenii commentarii</i>
Ps.-Plu. <i>Lib. Ed.</i>	Pseudo-Plutarchus, <i>De liberis educandis</i>
Schol. rec. Ar. <i>Nub.</i>	Scholia in Aristophanis <i>Nubes</i> (scholia recentiora Eustathii, Thomae Magistri et Triclinii)
Schol. anon. rec. Ar. <i>Nub.</i>	Ead. (scholia anonyma recentiora)
Schol. Tzetz. Ar. <i>Nub.</i>	Ead. (scholia recentiora Tzetzae)
Theoph. Cont.	Theophanes Continuatus, <i>Chronographia</i>

I also occasionally abbreviate Biton's *Kataskeuai* (*Constr.*), Pappus' *Synagoge* (*Syn.*) and Oribasius' *Collectiones medicae* (*Coll. Med.*).

References to Greek authors are made according to the standard citation systems of the *Thesaurus Linguae Graecae* (henceforth *TLG*), with the following exceptions:

(i) Hero's *Dioptra*, *Geometrica*, *Metrica* and *Pneumatica* are cited by page and line of the pertinent volumes of *Heronis Alexandrini opera quae supersunt omnia* (Leipzig 1899–1914; repr. Berlin 2011) unless reference is made to the whole chapter (abbreviated as 'ch.', pl. 'chh.');

(ii) Hero's and Philo's *Belopoeica* and Bito's *Kataskeuai* are cited according to the edition of Marsden (1971: 66-77), which has been reformatted compared to

¹ As noted by Whitehead (2016: 9 n. *), LSJ erroneously abbreviate all of Philo's extant works as '*Bel.*'.

the previous editions of Wescher and Thévenot. So, for example, Hero, *Bel.* 73.6 refers to page 73 in Wescher and to line 6 in Marsden (so also in the case of Bito's *Kataskeuai*), whereas Ph. *Bel.* 73.22 refers to page 73 in Thévenot and to line 22 in Marsden.

2. REFERENCES

References to the text are by chapter (Roman numeral) and section (Arabic numeral), with page and line numbers of the present edition given in square brackets (for an exception, see Introduction, §3 with n. 70). Citations of whole chapters or sections are made without reference to page and line number, unless the context otherwise requires (see Introduction, §5.1, and the synopsis headings in the Commentary on BOOK ONE). Cross-references to notes in my commentary follow the same citation system. When there is more than one commentary entry for the same line, cross-references to different notes are distinguished by citing the relevant portion of text in bold style. References to illustrations in this edition are shown in bold (e.g. **Fig. 1**).

3. PERIODICALS AND REFERENCE WORKS

Abbreviations of periodicals follow the conventions of *L'Année philologique*. The following abbreviations are used for standard reference works:

Bailly	A. B., <i>Dictionnaire Grec-Français</i> , Paris 1950.
Bécares Botas	V. B.B., <i>Diccionario de terminología gramatical griega</i> , Salamanca 1985.
Chantraine, <i>DELG</i>	P. C., <i>Dictionnaire étymologique de la langue grecque. Histoire de mots</i> , Paris 1968–1980.
Chantraine, <i>Form.</i>	P. C., <i>La formation des noms en grec ancien</i> , Paris 1933.
<i>CID</i>	<i>Corpus des inscriptions de Delphes</i> , Paris 1977–.
<i>CODM</i>	<i>The Concise Oxford Dictionary of Mathematics</i> , Oxford 2014 ⁵ (1990 ¹).

Denniston, <i>GP</i>	J.D. D., <i>The Greek Particles</i> , Oxford 1954 ² (1934 ¹).
<i>Didyma</i>	<i>Didyma Inscriptions. Texts and List</i> , ed. D.F. McCabe, Princeton 1985.
DS	C. Daremberg-E. Saglio, <i>Dictionnaire des antiquités grecques et romaines d'après les textes et les monuments</i> , Paris 1877–1919.
<i>DGE</i>	F.R. Adrados <i>et al.</i> , <i>Diccionario Griego-Español</i> , Madrid 1980–.
<i>FGrH</i>	<i>Die Fragmente der griechischen Historiker</i> , ed. F. Jacoby, Berlin 1923–1959.
Frisk, <i>GEW</i>	H. F., <i>Griechisches etymologisches Wörterbuch</i> , Heidelberg 1955–1972.
Forcellini	E. F., <i>Totius Latinitatis Lexicon</i> , Prato 1858–1875.
<i>GEL</i>	J.P. Louw-E. Nida, <i>Greek-English Lexicon of the New Testament Based on Semantic Domains</i> , New York 1988.
<i>GG</i>	<i>Grammatici Graeci</i> , Leipzig 1867–1910 (repr. Hildesheim 1965).
<i>HE</i>	A.S.F. Gow-D.L. Page, <i>The Greek Anthology. Hellenistic Epigrams</i> , Cambridge 1965.
<i>IC</i>	<i>Inscriptiones Creticae</i> , ed. M. Guarducci, Rome 1935–1950.
<i>ID</i>	<i>Inscriptions de Délos</i> , ed. A. Plassart <i>et al.</i> , Paris 1926–1972.
<i>IG</i>	<i>Inscriptiones Graecae</i> , Berlin 1873–.
KB	R. Kühner-F. Blass, <i>Ausführliche Grammatik der griechischen Sprache</i> , I. <i>Elementar- und Formenlehre</i> , Berlin 1890 ³ (vol. I), 1892 ³ (vol. II).
KG	R. Kühner-B. Gerth, <i>Ausführliche Grammatik der griechischen Sprache</i> , II. <i>Satzlehre</i> , Hannover/Leipzig 1898 ³ (vol. I), 1904 ³ (vol. II).

<i>LSAM</i>	<i>Lois sacrées de l'Asie Mineure</i> , ed. F. Sokolowski, Paris 1955.
<i>LSJ</i>	H.G. Liddell-R. Scott-H.S. Jones, <i>A Greek-English Lexicon</i> , Oxford 1940–1968.
<i>LSJ, Supplement</i>	P.G.W. Glare, <i>Greek-English Lexicon. Revised Supplement</i> , Oxford 1996.
<i>Milet</i>	<i>Milet. Ergebnisse der Ausgrabungen und Untersuchungen seit dem Jahre 1899</i> , ed. T. Wiegand, Berlin 1906–.
Mugler, <i>Dictionnaire</i>	C. M., <i>Dictionnaire historique de la terminologie géométrique des Grecs</i> , Paris 1958.
<i>OLD</i>	<i>Oxford Latin Dictionary</i> , Oxford 1968–1982.
<i>PG</i>	<i>Patrologia Graeca</i> , Paris 1857–.
Powell, <i>Coll. Alex.</i>	J.U. P. (ed.), <i>Collectanea Alexandrina</i> , Oxford 1925 (repr. 1970).
<i>RE</i>	<i>Paulys Real-encyclopädie der classischen Altertumwissenschaft</i> , ed. G. Wissowa <i>et al.</i> , Stuttgart 1893–Munich 1978.
<i>SEG</i>	<i>Supplementum Epigraphicum Graecum</i> , Leiden 1923–.
<i>TGL</i>	<i>Thesaurus Graecae linguae</i> , Paris 1831–1865.
<i>TLG</i>	L. Berkowitz-K.A. Squitier, <i>Thesaurus Linguae Graecae: Canon of Greek Authors and Works</i> , New York/Oxford 1990 ³ (Irvine, CA 1977 ¹).
<i>TLL</i>	<i>Thesaurus linguae Latinae</i> , Leipzig 1900–.
<i>VS</i>	<i>Die Fragmente der Vorsokratiker</i> , ed. H. Diels-W. Kranz, Berlin 1951–1952 ⁶ (1903 ¹).

4. EDITIONS AND TRANSLATIONS

In the apparatus criticus and in the commentary the abbreviation *ed. princ.* refers to the first edition of Hero's *Aut.* and *Spir.* (also referred to as Thévenot). The following editions and translations (listed chronologically) are cited by the name of the editor and/or translator only:

Baldi	B. B. (trans.), <i>Di Herone Alessandrino de gli automati, overo machine se moventi, libri due</i> , Venice 1589.
Thévenot	M. T. (ed.), <i>Veterum mathematicorum Athenaei, Apollodori, Philonis, Bitonis, Heronis et aliorum opera Graece et Latine pleraque nunc primum edita</i> , Paris 1693.
Couture	D. C. (trans.), <i>Heronis Alexandrini de automatorum fabrica</i> , in Thévenot 243-274.
Prou	V. P. (ed.), "Les théâtres d'automates en Grèce au II ^e siècle avant l'ère chrétienne d'après les ΑΥΤΟΜΑΤΟΠΟΙΗΚΑ d'Héron d'Alexandrie", <i>Mémoires présentés par divers savants à l'Académie des inscriptions et belles-lettres de l'Institut de France</i> , s. 1, 9.2 (1884) 117-274.
Schmidt	W. S. (ed.), <i>Heronis Alexandrini opera quae supersunt omnia</i> , I.1. <i>Pneumatica et automata</i> , Leipzig 1899.
Schmidt, <i>Supplementum</i>	W. S. (ed.), <i>Heronis Alexandrini opera quae supersunt omnia</i> , I.2. <i>Pneumatica et automata, Supplementum</i> , Leipzig 1899.
Murphy	S. M. (trans.), "Heron of Alexandria's <i>On Automaton-Making</i> ", <i>HTechn</i> 17 (1995) 1-44.

All emendations, deletions and transpositions have been cited in the apparatus critici and in the commentary by the name of their proposer only. J.F.

Boissonade's and B.J. Rozema's (proposed) supplements in *AP* 11.185.4 have been cited from Floridi (2014: 356, 360), whereas the reference to Commandino in my app. crit. to Papp. 1024.24-1026.2 is to Commandino (1588: 305). The conjectures of A. Brinkmann, H. Diels, F. Haase, P. Hildebrandt, H. Schöne, R. Schöne have been cited from Schmidt's edition of Hero's *Aut.*, except when it was possible to locate their original (or intermediary) source (see below).² F. Susemihl's supplement has been cited from Susemihl (1891: 744 n. 190). M. Egger's conjectures have been cited from Prou's edition of BOOK TWO of Hero's *Aut.*, although it is not clear whether the emendation at XXX.6 has been proposed by M. Egger or by É. Egger. (In his *Index*, Prou 255 refers to É. Egger, "Coup d'œil sur l'histoire des acteurs dans l'antiquité", in Id., *Memoires de littérature ancienne*, Paris 1862, 409-423, but I was unable to find any mention of the conjecture there.) Schmidt's and Prou's have been cited from their respective editions. Weil's have been cited from his review of Prou's original 1881 edition (Weil 1882: 420, 421, 422, 423), while Olivieri's critical observations have been cited from Olivieri (1901: 432, 433, 434). E.S. Forster's supplement (see Comm. on II.6 [10.4-8]) has been cited from Nussbaum (1976: 152). J.G. Schneider's correction (see Comm. on IV.1 [18.6]) has been cited from Schmidt's edition of Hero's *Spir.*, whereas G. Murray's conjecture (see Comm. on VI.3 [24.16-20]) has been cited from Biehl (1970: 47); for the emendations of C. Wescher and L. Dindorf, see Introduction, §4.1. The following abbreviations should be particularly noted:

Diels	for XXI.1 [68.12] and XXII.6 [72.20]: Schöne (1891: 75 n. 3, 76 n. 5)
Haase	for II.8 [12.1], XV.2 [52.16], XV.3 [54.2], XVI.2 [54.16-17], XX.3 [66.6], XXII.5 [72.13], XXIII.6 [78.3]: 'schedae Schoenianae'; for XX.1 [64.7]: Haase (1847a: 432 n. 34)

² Some of Haase's and R. Schöne's emendations were in turn cited by Schmidt from the so-called 'schedae Schoenianae' (on which, see Schmidt, *Supplementum* 12 n. 2), which I have been unable to locate (for these emendations, see below).

R. Schöne for XX.1 [64.5-6], XXIII.1 [74.7] and XXX.2 [106.14]: ‘schedae Schoenianae’; for XX.4 [66.17], XXI 2 [68.15], XXII 4 [72.3], XXII 6 [72.20], XXVIII 3 [102.1], XXIX 1 [104.17]: Schöne (1891: 75 with n. 4, 76 n. 5)

5. SECONDARY SOURCES

Secondary sources other than those listed in §§3-4 above are cited by author and date. Publications by two or three authors are referred to by the last names of all authors, separated by a hyphen. If a name contains a hyphen, an en dash is used instead. For works by more than three authors, only the name of the first author is cited, followed by *et al.* Multiple publications by the same author in the same year are distinguished by lowercase letters (a, b) after the year. For forthcoming works by the same author, Arabic numerals (1, 2) are used for the same purpose. English-language titles of cited works are capitalised headline-style, whereas titles in other languages are capitalised sentence-style.

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INTRODUCTION

1. THE AUTHOR

Nothing is known for certain about Hero's life except that he lived and worked in Alexandria, Egypt,¹ in the mid-first century CE. A highly erudite scholar,² he wrote numerous mechanical and mathematical treatises, most of which are extant either entirely or in part.³ His corpus includes works on pneumatics (*On Water-clocks*, *Pneumatica*),⁴ artillery (*Belopoeica*),⁵ land-surveying (*Dioptra*), geometry (*Definitions*, *De Mensuris*, *Geometrica*, *Metrica*, *Stereometrica*),⁶

¹ The geographical location is inferred from the epithet Ἀλεξανδρεὺς. For the evidence and discussion, see Giardina (2003: 6-7 nn. 5-6). See also below, §4.

² On Hero's erudite profile, see Vitrac (2009: esp. 191-5).

³ For a full account of Hero's works, see Giardina (2003: 31-74), who distinguishes between 'mathematical works' and 'technological works', the latter being further subdivided into 'technologico-theoretical' and 'technologico-practical'. As Giardina (2003: 34) herself notes, her classification is based on modern epistemological assumptions. See Vitrac (2009: 156) for some cautionary remarks about the inadequacy of application of the distinction between mathematical and technical to the ancient situation.

⁴ The *Pneumatica* was intended as a sequel to a four-volume work on water-clocks (*Spir.* 2.12-15), of which only scanty fragments are preserved in Pappus' commentary on Ptolemy's *Almagest* and Proclus' *Hypotyposis*. These fragments have been edited by Schmidt (below, §2.1). On the title of this work, see below, n. 108.

⁵ I do not include in my study the fragmentary treatise attributed to Hero and commonly known as *Cheiroballistra*, since the general scholarly consensus regards it as spurious. The Heronian authorship has been accepted by Prou (1877) and Marsden (1971: 206-33), who both edited, translated and commented on the work. For a more recent edition, translation and discussion, see Wilkins (1995). The most recent reconstruction of the *cheiroballistra*, a hand-held arrow-shooter, has been proffered by Iriarte (2000), who also carefully discusses previous reconstructions.

⁶ The *De Mensuris*, *Geometrica* and *Stereometrica* underwent alterations at the hands of later writers, but it is difficult to distinguish between original and interpolated material. Likewise, in Byzantine times the *Definitions* was augmented with material from other sources, but in this case it is easier to draw a line of demarcation (*Deff.* 1-132 vs 133-8). There has been some debate about the authenticity of this work (Giardina 2003: 83-4), which has culminated in Knorr's (1993) suggestion that its author was the mathematician Diophantus of Alexandria, traditionally dated to the mid-to-late third century CE (but see Knorr 1993: 184-5, 187 for the suggestion that he lived either in the early-mid third century or in the first century CE; as noted by Klein 1968: 248, a first-century CE date was first proposed by Bachet 1621 in his *Epistola ad Lectorem*). The grounds for this attribution are as follows: (1) both the *Definitions* and Diophantus' *Arithmetic* are dedicated to a Dionysius; (2) the prefaces to these treatises show similarities in content and style. Neither (1) nor (2) proves conclusively that Diophantus wrote the *Definitions* both because Dionysius was a very common name (in either case he is addressed with a different title) and because both authors represent to a certain extent a common 'Oriental' Hellenistic tradition; see Neugebauer (1969: 178-9). The similarities between the prefaces

catoptrics (*Catoptrica*),⁷ and applied and theoretical mechanics (*Automata, Baroulcos, Mechanica*).⁸ The date of his activity has been long debated, with suggestions ranging from the first century BCE to the third century CE.⁹ A consensus was reached after Neugebauer (1938: 22-3) demonstrated that Hero was earlier than Ptolemy (*fl.* 127–148 CE), and that the lunar eclipse (not a ‘Sonnenfinsternis’, Asper 2001: 136) mentioned in ch. 35 of his *Dioptra* is an actual eclipse that occurred on 13 March 62 CE.¹⁰ The so-called ‘Heronian question’ has received renewed attention in more recent years, and Sidoli (2011) took pains to show that the date of 62 CE can only be taken as a *terminus post quem* for Hero’s activity. Although many of his observations remain valid, it is worth examining the question in some detail.

Sidoli’s (2011) main argument is that the eclipse data in *Dioptr.* ch. 35 do not correspond to an accurately recorded observation that can be attributed (at least with any certainty) to Hero. His aim, therefore, is to partly refute Neugebauer’s (1938: 23) earlier argument, which he contends depends upon three claims: (1) the mathematical methods of *Dioptr.* ch. 35 are purely nomographic and the eclipse of 62 CE, being ‘ill-suited’ to such methods, must have been used as an appeal to the recent memory of his readers;¹¹ (2) the data stated in *Dioptr.* ch. 35 refer to an eclipse that Hero himself observed, despite the fact that he does not explicitly state this; (3) the lunar eclipse of 13 March 62 CE

suggest to me a relation of direct dependence between the two. On the addressee of the *Definitions*, see, more recently, Asper (2001), who proposes to identify him with the first-century CE grammarian Dionysius of Alexandria (Suda δ 1173; Matthaïos 2015: 226, with further bibliography).

⁷ The *Catoptrica*, which was previously attributed to Ptolemy, is preserved in a – probably abridged – Latin translation by William of Moerbeke. For a recent edition and English translation, see Jones (2001), who (pp. 150-51) raises doubts about the authorship.

⁸ The *Mechanica* survives in Arabic translation, as well as in fragments preserved in Pappus’ *Mathematical Collection*. The *Baroulcos*, which was originally a separate work, has been transmitted as part of both the *Mechanica* (*Mech.* 1.1) and the *Dioptra* (ch. 37); see Drachmann (1963a: 22-32).

⁹ For a summary of the main positions, see Giardina (2003: 8-25). These chronological limits were set by the fact that Hero cites several times Archimedes and is cited by Pappus.

¹⁰ In a recent article, Masià (2015) argued that the eclipse has no evidential value for the purposes of dating Hero. The problems associated with Masià’s argument are discussed in **Appendix 5**.

¹¹ Neugebauer (1975: 846) amplifies this point, suggesting alternatively that Hero might have appealed to his own memory. Sidoli (2011: 60) defines nomographic methods as ‘some tradition of using techniques of ancient geometry to produce line segments or arc lengths on an instrument in such a way that they could then be measured by an analog measuring tool’.

is the only one in the range of dates in which Hero might possibly have been active that gives a good fit for the data provided in the text.¹² In order to prove his argument, Sidoli (2011: 57-8) points out that the eclipse data in *Dioptr.* ch. 35 are too vaguely formulated (*contra*, Giardina 2003: 18), which, as he maintains, accords neither with the standards of precision found in other ancient technical works nor with the method of finding the great-arc distance between two locations (in Hero's own example, Alexandria and Rome) set out in that chapter. From these and other observations, he concludes that the reason why that particular eclipse was chosen is that it had been seen in both cities by the contemporaries of Hero or his source, and that Hero might in fact have drawn the eclipse data from the latter (Sidoli 2011: 59). While this argument is cogent, it only indicates that the year 62 CE is a *terminus post quem* for Hero's *Dioptra*, not for his activity as such. There are at least two problems with it. First, it misattributes claim (2) to Neugebauer (1938: 23).¹³ Hero's autopsy of the eclipse was first inferred by Drachmann (1948: 76),¹⁴ and was later independently suggested as a possibility by Neugebauer (cf. above, n. 11). In his earlier study, Neugebauer (1938: 24) only concluded that 'man Heron entweder an das Ende des ersten Jahrhunderts n. Chr. setzen muss oder alle Daten zwischen etwa – 100 und + 200 als gleichwahrscheinlich ansehen kann'.¹⁵ Second, it fails to take account of other pieces of internal evidence used for dating Hero. The evidence can be summarised as follows:

(a) Hero, *Mech.* 3.20 describes a direct screw press with a female screw cut into its beam, a device which Plin. *Nat.* 18.317 says was invented twenty-two years before his time. This, together with Hero's description of the screw-cutter (*Mech.* 3.21),¹⁶ establishes a *terminus post quem* of 55 CE for the *Mechanica*.¹⁷ This date has been corroborated by Drachmann (1932: 125-8), who called

¹² These three claims are quoted, almost unaltered, from Sidoli (2011: 55).

¹³ The same mistake has been made by Vitrac (2009: 155).

¹⁴ This has already been noted by Keyser (1988: 218 with n. 5).

¹⁵ In subsequent studies, Neugebauer (1969: 178; 1975: 846) decisively opted for the former alternative.

¹⁶ Drachmann (1963a: 140) finds it likely that the screw-cutter, a device for cutting female screw threads, was Hero's own invention.

¹⁷ Schmidt XIX, XXII-III. Keyser (1988: 218) cautions that Schmidt's argument is valid only if the screw-cutter was published for the first time in the *Mechanica* (which would indeed be the case had Hero invented it; see above, n. 16) and if Pliny had found out about it only through published works.

attention to the fact that another instrument described by Hero, *Mech.* 3.16-17, the so-called *galeagra*,¹⁸ is referred to by Plin. *Nat.* 15.5 as *nuper inventum*;¹⁹

(b) Suet. *Nero* 41.2 and D.C. 63.26.4 both mention a new type of water-organ that was demonstrated in 68 CE in Rome. A comparison with Hero's water-organ (*Spir.* ch. 1.42) has led Keyser (1988: 219-20) to suggest that the new model was Hero's own invention, which, in turn, would provide an approximate date for the publication of the *Pneumatica*.²⁰ 'Composition' is more correct than 'publication', given that the *Pneumatica* was in all likelihood published posthumously (cf. below, §5.7);

(c) In ch. 25 of his *Dioptra*, Hero employs Eratosthenic, rather than Posidonian, measurements of the circumference of the Earth. This gives a *terminus ante quem* of c.114 CE for the *Dioptra*, since it was then that the mathematician/geographer Marinus of Tyre introduced the Posidonian measurements in Alexandria;²¹

(d) The first Hebrew treatise on mensuration, the *Mishnat ha-Middot*, which was composed no later than 150 CE, shows a strong Heronian influence in terms of subject matter (Gandz 1940). This provides a *terminus ante quem* for the *Metrica*.

This evidence alone suffices to show that Hero was active between the years 55 and 114–150 CE, and so there seems to be no reason to doubt that the eclipse of 62 CE, whether Hero observed it or not, occurred during his lifetime. As far as (b) is concerned, it should be noted that while the water-organ was first invented by Ctesibius, who lived in the early to mid-third century BCE,²² Hero's model was most probably based on an earlier prototype by Ctesibius' successor Philo of Byzantium.²³ Unfortunately, we have no means of knowing what Philo's device looked like, and Drachmann (1948: 100) believes that the differences between the Ctesibian and the Heronian versions are so slight that it is of little importance that we cannot distinguish between Philonian and Heronian

¹⁸ The *galeagra* was a wooden bin used for holding the olive pulp. Hero describes two versions of it; see Drachmann (1963a: 122-6).

¹⁹ Drachmann's argument is summarised in Drachmann (1948: 75). Sidoli (2011: 59 n. 2) is aware of Schmidt's and Drachmann's arguments.

²⁰ Keyser's argument has been accepted by Raios (2000: 35) and Giardina (2003: 27-8).

²¹ Krafft (1973: 16), cited by Asper (2001: 136 n. 14).

²² On Ctesibius, see further below, §5.3.

²³ On Philo, see further below, §§2 and 5.3.

improvements.²⁴ What is certain, however, is that the improved version of the device had only recently been introduced in Rome, as one can infer from Suetonius' words (*organa hydraulica novi et ignoti generis*, Suet. *Nero* 41.2). The date of 68 CE, therefore, must be regarded as a *terminus ante quem* for the introduction of the new model into imperial circles rather than for either its invention or, for that matter, the publication of the *Pneumatica*.

An attempt to narrow down the chronological range of Hero's activity has been made by Raïos (2000). He adduces two main pieces of evidence in support of a Neronian date (Raïos 2000: 29-31, 34-6). The first is the inauguration of two (unfinished) construction projects, namely, the canal from Lake Avernus to the mouth of the Tiber (probably started in 64 CE) and the canal through the Isthmus of Corinth (67 CE).²⁵ In particular, the construction of the latter would provide a more secure *terminus ante quem* for the *Dioptra* on the basis of the assumption that the Egyptian geometers forming Nero's entourage (Ps.-Luc. *Ner.* 4 = 221.27 Kayser) included Hero. Clearly, this is highly speculative, and the fact that some of Hero's problems deal with hypsometric differences and the digging of a tunnel cannot be taken as a definitive indication of Hero's involvement in either project.²⁶ And even if he did take part in the design and/or construction process, it does not follow that he composed his *Dioptra* before the years 64–67 CE. The second piece of evidence is the fact that Nero sung the role of Nauplius (Suet. *Nero* 39.3), whose myth, as will be seen, is displayed in Hero's stationary automaton. The value of such evidence depends on the interpretation of a poem by the first-century CE epigrammatist Lucillius (*AP* 11.185) as alluding to Nero's performance, a performance which would have taken place during his journey to Greece (67 CE). This would establish either a *terminus ad quem* or a *terminus ante quem* for the composition or even the publication of the *Automata*.²⁷ But let us look at Lucillius' epigram:

²⁴ For the differences between Ctesibius' and Hero's water-organs, see Drachmann (1948: 7-9). Keyser (1988: 219) is inclined to think that, in addition to using horn for the valve-springs instead of iron, Hero introduced several improvements in technical details.

²⁵ On the former, see Arata (2014); on the latter, see Werner (1997: 114-16).

²⁶ Pace Raïos (2000: 30-1 with nn. 54-6), who refers to *Dioptr.* 204.25-8 (hypsometric differences), 234.19 (height of a ditch) and 238.3-4 (digging of a tunnel). On tunnels, see also *Dioptr.* chh. 16 and 20.

²⁷ For the tentative suggestion that the *Automata* was published posthumously, see below, §5.7.

Ἑλλήνων ἀπέλυε πόλιν ποτέ, δέσποτα Καῖσαρ,
 εἰσελθὼν ᾄσαι Ναύπλιον Ἑγέλοχος.
 Ναύπλιος Ἑλλήνεσσιν ἀεὶ κακὸν ἢ μέγα κῶμα
 <***> ἢ κιθαρωδὸν ἔχων.

4 lacunam fere octodecim litterarum praebet **P** : <καὶ πυρσὸν ψεύστην> dub. Floridi coll. Crinag. *AP* 9.429.3-4 et Bass. *AP* 9.289.3 : <καὶ φρυκτοὺς ψευδεῖς> vel <ἐκ φρυκτῶν ψευδῶν> Rozema : <νηυσὶν ἐπεμβάλλων> Boissonade

Hegelochus, my Lord Caesar, once relieved a city
 from the Greeks by coming on stage to sing of Nauplius.
 Nauplius is always an evil to the Greeks, either bringing a great wave
 <***> or bringing a citharist.

The reference to a performance centred around the character of Nauplius has led most scholars to think that Lucillius is satirising Nero through the figure of the tragic actor Hegelochus,²⁸ and hence that the words Ἑλλήνων ἀπέλυε πόλιν (line 1) refer to Nero's proclamation of freedom and tax immunity for Greece (67 CE; Suet. *Nero* 24.2; *IG* 7.2713.12-14).²⁹ This interpretation has been rightly challenged on the following grounds: (1) the myth of Nauplius was a rather popular subject in the early Imperial period, and we know that Nero performed other traditional tragic roles (Suet. *Nero* 21.2-3);³⁰ (2) the repeated addresses to Καῖσαρ in the Lucillian corpus should be understood as reminders that Nero is the primary addressee of the book rather than as clues to a hidden satire;³¹ (3) the inclusion of the poem among epigrams about incompetent singers and actors (*AP* 11.186-9; cf. lemma to *AP* 11.185 [B] εἰς κιθαρωδούς, ἀλλὰ μὴν καὶ τραγωδοὺς καὶ κωμωδοὺς) indicates that Ἑγέλοχος (line 2) is not a fictive name.³² Thus, the epigram should simply be read as a satire of Hegelochus, and there

²⁸ Hegelochus was famous for having mispronounced E. *Or.* 279 in the first performance of the tragedy in 408 BCE. The episode is famously ridiculed by Ar. *Ra.* 303-4; for a discussion of Hegelochus' error and other *testimonia*, see Csapo-Slater (1994: 267-8).

²⁹ For Nero's philhellenic agenda behind the event, see Enos (2013: 47); *contra*, for instance, Alcock (1993: 16).

³⁰ Floridi (2014: 357-8).

³¹ Gutzwiller (2005); cf. also Floridi (2014: 78-9), with references. The most common interpretation is that the address δέσποτα Καῖσαρ in *AP* 11.185.1 refers to Vespasian rather than to Nero; see Floridi (2014: 357).

³² Gutzwiller (2005), whose position has been endorsed by Floridi (2014: 358).

would be no reason to connect Nero's performance with the mythical display of Hero's stationary automaton. The year 67 CE, as a result, does not constitute a chronological indication for the *Automata*.³³

2. EDITIONS AND TRANSLATIONS OF THE *AUTOMATA*

The history of the editions and translations of the *Automata* is a complex one. The reasons for this are threefold. First, it is intimately connected with questions concerning the history of the text. The surviving manuscripts of the treatise, most of which are late and of ancillary importance for the *constitutio textus*, show a disruption of the order of chh. XXII-XXV.³⁴ This issue was not recognised as such until 1882, when H. Weil (1818–1909) published a review of Prou's original edition of Book Two which, among other things, constitutes a valuable source of emendations (Weil 1882). Second, the first translations of the work antedate the *editio princeps* by more than a century and were based on Greek exemplars that have not yet been identified. This means that these translations should be treated as a source of critical information. Third, Hero's debt to Philo of Byzantium (*fl.* c.200 BCE), from book 6 of whose work (now mostly lost) our author derived much of his material on the stationary automaton, has been acknowledged not before the end of the nineteenth century (Schöne 1891; cf. below, § 5.6). The obvious implication of this is that the first attempts to edit the second part of the treatise (which is more problematic textually when compared with the first) did not take into account the surviving portions of Philo's work: of his eight- or nine-book compendium of mechanics entitled *Μηχανικὴ σύνταξις* (*Mechanical Collection*) there survives, in the original Greek, only the fourth book on artillery construction (*Βελοποιϊκά*),

³³ Marshall (2003: 263 with n. 9) feels that the treatise postdates more strictly technical works such as the *Dioptra*, and hence he tentatively suggests an early Flavian date.

³⁴ On such disruption, and on the attempts to restore the original chapter order, see below, §3.2, and esp. nn. 84 and 86.

along with substantial excerpts from the seventh and eighth books, concerning, respectively, fortifications (*Παρασκευαστικά*) and siegecraft (*Πολιορκητικά*).³⁵

2.1 Editions

The treatise was edited for the first time by M. Thévenot (1620–1692), Ph. de la Hire (1640–1718) and J. Boivin de Villeneuve (1663–1726) in Thévenot 243-74. The text of their edition, which contains facing Latin translation by D. Couture (dates unknown), is largely unsatisfactory, because it is based on three relatively late and inferior manuscripts: **Pa**, **Pd** and **Pf**. However, despite his marked reluctance to emend (see Thévenot VI), Thévenot has corrected the text in a few places (II.9 [12.13], VII.2 [26.13], IX.1 [30.6] and [30.9]), while in others he appears to have derived his (variant) readings (or corrections) from the equally late manuscripts **Pc**, **Pe** and **Pg**.³⁶ The illustrations are copied from Baldi's drawings, occasionally modified in small details and reversed horizontally.

A little more than a century and a half later, in 1847, F. Haase (1808–1867) announced a complete re-edition that was part of a larger project consisting of a six-volume collection of works by military and mechanical

³⁵ The arrangement of Philo's *Mechanical Collection* was first elaborated by Haase (1847a) and later by Orinsky-Neugebauer-Drachmann (1941). These reconstructions, which are mainly based on the presence of cross-references in the extant portions of the work, agree on the order of the books. Curiously, Whitehead (2016: 20-1) does not mention either of these reconstructions, but he (p. 21 n. 19) does refer to Garlan (1973: 16-18; 1974: 283-4) for the controversies concerning the order of books 5-9. Although there is some variation in the titles of individual books, most notably in the title of book 6 (below, n. 123), the generally accepted arrangement is as follows (asterisked titles are not attested in Philo): 1. *Εἰσαγωγή*, 2. *Μοχλικά*, 3. *Λιμενοποιϊκά*, 4. *Βελοποιϊκά*, 5. *Πνευματικά*, 6. **Αὐτοματοποιητικὰ* Αὐτοματοποιϊκά*, 7. *Παρασκευαστικά*, 8. **Πολιορκητικά*, 9. *Περὶ ἐπιστολῶν* (unless this was a separate treatise). Book 5 is preserved in Arabic translation (translated into French and English, respectively, by Carra de Vaux 1902 and Prager 1974) and in a partial Latin translation of another (lost) Arabic version (fully translated into German by Schmidt: see below, §2.1; for a selective English translation, see Prager 1974: 79-91, 127-233). Further references in Rance (2016). On the subject-matter of book 6, see below, n. 126.

³⁶ Some of these readings are correct (*ἀποπορείαν*, V.2 [20.14]; *ἀνοιγόμενον*, XIV.1 [50.21]; *ἐν*, XXVI.2 [90.14]), but of course it is debatable whether Thévenot (or either of the other two editors) took all of them from the manuscripts. In at least two cases (V.2 [20.14] and XXVI.2 [90.14]), they may be due to conjectural emendation. See, by contrast, the erroneous readings *περιφερὴς* (III.2 [16.8]) and *ἀνεχθήσονται* (XXIII.5 [76.17]).

writers.³⁷ Although none of the projected volumes ever appeared, the announcement remains valuable as an indication of a renewed interest in the works by Hero. Haase intended to use manuscripts (**Ae**), **Mc**, **Pa**, **Pc**, **Pe**, **Pf**, **Pg** and **Ph** as the basis for his edition.³⁸

In 1881 the civil engineer V. Prou (1831–1884) re-edited the second part of the treatise on the basis of seven Paris manuscripts (**P₁–P₇** = **Pa**, **Pb**, **Pd**, **Pe**, **Pf**, **Pg** and **Ph**): “Les théâtres d’automates en Grèce au II^e siècle avant l’ère chrétienne d’après les ΑΥΤΟΜΑΤΟΠΟΙΙΚΑ d’Héron d’Alexandrie”, *Mémoires présentés par divers savants à l’Académie des inscriptions et belles-lettres de l’Institut de France*, s. 1, 9.2 (1881); reprinted, apparently unaltered, as part of an enlarged issue of the same publication in 1884 (erroneously catalogued under the year 1878 at BNF, *Gallica*, <http://gallica.bnf.fr/ark:/12148/cb32813503c/date18780101>).³⁹ This publication has a quadripartite structure. In the introduction (‘Introduction historique’), Prou reviews Magnin’s (1852) book on the history of European puppetry (which he criticises for not mentioning Hero’s work) and discusses previous and contemporary scholarship on the *Automata*, most notably the first two translations of the treatise (respectively, by Baldi and D’Auria; see below), the *editio princeps* and the contribution of Martin (1854). Immediately following the introduction, Part One (‘Première partie’) provides observations on the manuscripts used in the edition, addresses the issue of the disrupted chapter order (albeit without understanding it) and discusses the two types of automaton distinguished by Hero – ‘mobile’ (ῥπαγον) and ‘stationary’ (στατόν) – against their mythical and theatrical background. Part Two (‘Deuxième partie’) furnishes a technical examination of the mechanisms described, or alluded to, in the treatise, and formulates an engineering theory of how (repeated) motion is imparted by means of the counterweight (‘théorie des cordons moteurs des automates d’Héron d’Alex-

³⁷ See Haase (1847b: esp. 9–10). In addition to the *Automata*, Haase planned to publish (vol. 3) the following Heronian or pseudo-Heronian works: *Baroulcos*, *Belopoeica*, *Cheiroballistra* and *Dioptra*.

³⁸ Of these, he fully inspected (**Ae**), **Pa**, **Pc**, **Pe**, **Ph** and partially collated **Mb**, **Pf** and **Pg**. Schmidt’s account (*Supplementum*, 138) is not only incomplete but also incorrect: in addition to omitting **Mb**, it includes **Pe** among the partially collated manuscripts.

³⁹ Murphy 8 is wrong in claiming that Prou’s edition was republished as a book in 1884. Both COPAC and Google Books records suggest instead that it is the original edition that was published as a separate volume.

andrie').⁴⁰ Part Three ('Troisième partie') contains the Greek text with French translation underneath it and footnotes mainly devoted to linguistic and philological matters. The edition closes with an analytical index of topics, persons and Greek words; Part Two and Part Three comprise modern illustrations (some of which appear more than once), whereas Part One and Part Two include partial quotations and translations of BOOK ONE. The main contribution of Prou's edition to scholarship lies in the emphasis he places on the relevance of Hero's automata both to the history of theatre and to the history of technology. All too often, however, he has a very poor understanding of Hero's mechanisms (for two notable exceptions, cf. Comm. on V.3 [22.2-3] and IX.5 [32.8-9]), offers implausible or even absurd reconstructions, and fails to provide evidence to support them.⁴¹ As a result, despite a relatively good number of improvements and corrections, Prou did not lay solid foundations for an adequate understanding of the text.⁴² Some of his conjectures are ungrammatical,⁴³ while others are either unconvincing (for instance εἴλημα, XXV.5 [88.4]) or altogether wrong (for instance παραχθέντα, XXIII.8 [78.16]). His footnotes do not always specify whether the readings adopted in the text and not found in the *editio princeps* derive from the manuscripts. The availability of Prou's 1881 edition is very limited. In Europe I know of copies of the original edition in only three university libraries: Freie Universität Berlin (borrowable),⁴⁴ University College London (not borrowable) and Université Paris-Sorbonne (not borrowable).⁴⁵

The decisive turning point in the editorial history of the *Automata* came in 1899, when W. Schmidt (1862–1905) published the first volume (divided into

⁴⁰ This theory has not been taken into account in the present study because it requires advanced mathematical skills which I do not possess.

⁴¹ See already Schmidt, *Supplementum* 139, who cites as examples of Prou's misunderstanding of the Heronian principles his emendations of the text of II.2 [6.14-15] and VI.1 [22.22-24.3]. In addition to my observations on these passages, see my Comm. on XIV.2 [52.5-6] and XVI.3 [56.1-2], as well as my synopses on XIII.1-7 [44.15-48.13] and XIII.7-9 [48.13-50.15].

⁴² An opinion already held by Schmidt, *Supplementum* 139.

⁴³ These are προσκωλύσαντες (VI.2 [24.13]), ἡνοιγμένον (XIV.1 [50.21]), περιγνοίης (XXIV.6 [84.10]), ἀποτεμνόντας (XXVI.3 [92.8]) and ὑποστρεφόντας (XXVI.4 [92.12]).

⁴⁴ Only internal members of the university are eligible to borrow the item, but anyone can consult it *in loco*. I thank I. Kirsch, librarian of the Philologische Bibliothek of the Freie Universität Berlin, for the information (personal communication, January 7, 2019).

⁴⁵ In the present edition, I refer to Prou's 1884 reprint. Unfortunately, because I also refer to Weil's 1882 review of Prou's original edition, this creates an inconvenient anachronism.

two parts) of the Heronian *opera omnia* (Teubner). The first part includes, in addition to the *Pneumatica* and the *Automata*, the text, with apparatus criticus, facing German translation and footnotes, of (a) the exiguous fragments of Hero's four-volume work on water-clocks as preserved in Pappus' commentary on Ptolemy's *Almagest* (*in Ptol.* 87.9-88.10 and 89.4-5) and Proclus' *Hypotyposis* (*Hyp.* 4.74-7), (b) the Latin version of Philo of Byzantium's *Pneumatica*, and (c) Vitruvius' *De Arch.* 1.6.2, 9.9.2-5 and 10.12-13 (all relating to pneumatics). The second part (*Supplementum*) is mainly devoted to the manuscript tradition of Hero's twin treatises, and contains an extensive word index to the entire edition. Schmidt's edition can be considered as the only serious attempt to approach the text in a systematic and scholarly fashion. He consulted manuscripts which were apparently unknown to his predecessors (in his apparatus criticus and throughout his discussion of the history of the text sigla are used only for those manuscripts which he considered to be superior, on which see below, §3), made use of almost all of Haase's collations (which had been made available to him through R. Schöne⁴⁶ and were previously unknown to Prou), and printed the text of chh. XXII-XXV in the correct order (though, lamentably, he was not aware of Weil's reconstruction, which is clearly preferable to that of R. Schöne). He greatly improved the readability and presentation of the text (to wit, he punctuates far better than Thévenot and Prou and adopts a text layout that is not just more faithful to that of the manuscripts but also more perspicuous),⁴⁷ although his approach to conjectural emendation appears to have been rather erratic: at times he does not emend where emendation is required (see, for instance, the retention of the manuscript reading ἐπειλησόμεθα, VI.2 [24.12]), at other times he intervenes too rashly (see, for instance, the emendation ὅς' ἂν for ὅσα, II.3 [8.3]), and at yet other times he proposes emendations that are unsupported (see, for instance, the conjecture ἔν τῷ for ἐν τῷ, XVI.3 [56.1]) or poorly supported (see, for instance, the suggested addition of <ἀρμόζουσιν> at XXI.2 [68.19]). His apparatus criticus records emendations by previous scholars whose first source may be difficult to locate, but contains errors, oversights and omissions (for example, he does not acknowledge readings found in Prou's edition and

⁴⁶ See Schmidt, *Supplementum* 12 n. 2.

⁴⁷ On the text layout of previous editions, see below, §5.1.

instead treats them as his own conjectures).⁴⁸ Schmidt was the first to discuss the text in relation to (at least some) manuscript diagrams and to comment on the modern illustrations included in his edition (see his “Anmerkungen zu den Automaten, insbesondere zu den Figuren”, pp. LI-LXX, which shall be here referred to as *Anmerkungen*; he provides a similar set of observations for the *Pneumatica* at pp. XXVI-L). These illustrations, however, which were drawn by H. Querfurth (dates unknown), are not always based on the manuscript diagrams, and not infrequently include more details than are warranted by the text. Schmidt’s edition has three major drawbacks: (1) he did not include photographic reproductions of the manuscript diagrams (half-tone photo-reproduction processes had only recently become a regular feature of mass-market periodicals, were rather expensive, and would probably not have yielded satisfactory results)⁴⁹ but instead included only a small number of graphic reconstructions; (2) he provided only a partial and at times erroneous account of the history of the text, without undertaking a thorough stemmatic analysis of the manuscripts known to him either directly or indirectly; (3) he was excessively inclined to invoke interpolation in a way that ignores the multi-layered and incompletely revised nature of the text.

2.2 Translations

The first translation of the *Automata* into a Western language appeared in the sixteenth century when B. Baldi (1553–1617),⁵⁰ mathematician and polymath from Urbino, made a translation into Italian, accompanied by explanatory and textual endnotes, illustrations ultimately based on the manuscript diagrams, and a prolegomenon tracing the history of automata-making (“Discorso di chi traduce sopra le machine se moventi”).⁵¹ Originally a project of his master F.

⁴⁸ All these errors are collected in **Appendix 2**.

⁴⁹ For the history of half-tone technology, see e.g. Twyman (1970: 31-2).

⁵⁰ Recent years have seen a surge of interest in Baldi’s life and works: see Nenci (2005), Cerboni Baiardi (2006) and Siekiera (2009; 2010).

⁵¹ Baldi’s translation has been recently studied by Micheli (2005). This article contains much valuable information on Baldi’s situation within the Renaissance and the scholarship of the time, but is not unproblematic, especially in relation to its treatment of Baldi’s endnotes.

Commandino (1509–1575),⁵² the translation was completed in 1576 and published in 1589 under the aegis of the dedicatee of the work, G. Contarini (1536–1595).⁵³ This publication most probably encouraged Baldi's contemporary, the Neapolitan mathematician J. D'Auria (*fl.* c.1590),⁵⁴ to undertake a Latin translation of the whole treatise (date unknown), now preserved in the seventeenth-century manuscript Parisinus gr. 2380, ff. 211^r–241^v.⁵⁵ During the last decade of the century, after the publication of his first translation, Baldi retranslated the treatise into Italian. This second translation, preserved in the autograph manuscript Laurentianus Ashburnham 1525 (*Due libri di Herone Alessandrino delle machine da se operanti*,⁵⁶ saec. XVI), has remained unpublished.⁵⁷ Shortly afterwards, in 1601, Baldi published in Venice a minimally revised version of his first translation, under the title *Di Herone Alessandrino de gli automati, overo machine se moventi, libri due, nuovamente ristampato e con ogni diligenza ricorretto*.⁵⁸ Baldi's unpublished translation has

⁵² Baldi mentions this in his *Vita di Herone Alessandrino* (Ambrosianus D 332 inf., f. 107^r).

⁵³ For the date of the translation's completion, see the colophon at p. 41^v. Prou 121 erroneously cites the year 1569.

⁵⁴ D'Auria was particularly famous for his Latin translations of Autolycus of Pitane, Euclid and Theodosius of Bithynia, all published in Rome in the years 1587–1591 (Prou 121–2). For further biographical information, see Toppi (1678: 145).

⁵⁵ Unfortunately, this translation became available to me too late (February 7, 2019) to be fully incorporated into the present edition. The colophon at the end of the manuscript (f. 241^v) indicates that D'Auria's exemplar was a Vaticanus.

⁵⁶ A caveat is in order here. This translation was first catalogued under the erroneous title *Due libri d'Herone Alessandrino, delle machine da se operante* (cf. no. 1525 in *Catalogue* 1853, unpagged), which was later corrected to *Due libri di Herone Alessandrino, della machina da se operante* (*Relazione* 1884, available online at <http://www.bmlonline.it/la-biblioteca/cataloghi/fondo-ashburnham-catalogo>). Micheli (2005: 248), who seems to have consulted the manuscript, has *Due libri di Herone Alessandrino delle machine da se operanti*. I myself do not know the correct form of the title because, unfortunately, I have been unable to examine the manuscript. The form cited by Micheli is certainly the most plausible, for it is consistent with the title of Baldi's original translation.

⁵⁷ The approximate date of the translation suggests itself from Baldi's statement that he had retranslated the *Automata* and (once again) dedicated his translation to Contarini (Laur. Ashb. 1525, f. 2^{r(?)}, cited in Micheli 2005: 248).

⁵⁸ Scholars have been divided into several camps: those who regard Baldi's 1589 and 1601 translations as identical (G. Mazzucchelli, cited in Affò 1783: 168–9; Martin 1854: 40; Micheli 2005: 249), and hence claim that the only difference between the two is in the frontispiece; those who find no significant differences between them (Schmidt, *Supplementum* 140 n. 2); and those who consider them to be completely or significantly different from each other (P. Paitoni, cited in Villa 1767: 481 n. (I); Affò 1783: 169). I have selectively collated the two translations against each other, and have only very rarely found minor stylistic differences. For this reason, and

been erroneously considered as the autograph copy of either the first or the third translation:⁵⁹ in his manuscript preface Baldi is explicit that he had based his first translation on a manuscript belonging to Commandino and that, in order to retranslate the treatise, he compared this manuscript with a manuscript that belonged to G. V. Pinelli (1535–1601).⁶⁰ Two further translations are reported to have appeared, respectively, in 1647 (Bologna) and 1661 (place of publication unknown).⁶¹

Baldi's 1589 translation is of primary interest because it represents the first serious attempt to make sense of the Heronian text. As Baldi 3^r himself states, his rendering was based on a very corrupt manuscript. As a result, his translation leaves much to be desired in terms of internal coherence and soundness, but it is nonetheless generally accurate, showing peculiar sensitivity to technical language.⁶² Although not free from mistranslations and misunderstandings, particularly with reference to architectural or mechanical descriptions, it contains a number of corrections which are unlikely to be based upon readings of his exemplar and which have been either found in other manuscripts or confirmed by later conjectures (see, for example, my Comm. on II.7 [10.11-14]). Baldi's endnotes are typically informative and succinct, explicating his translation practice and elucidating (albeit not always successfully) problematic passages or less familiar words (his failure to make acceptable sense of the text is exemplified by his imaginative comments on the corrupt words τοὺς τῶν δαιμόνων χρόνους: VI.3 [24.19]; see Comm. on VI.3

because digitised copies of Baldi's 1601 translation are of lower quality, in the present edition I consistently refer to the earlier, unrevised version. It is worth noting that both the preface, which is dated February 1, 1589, and the colophon are reproduced unaltered in the revised edition.

⁵⁹ For the former misapprehension, see Rose (1975: 246); for the latter, see Libri (1841: 72 n. (1)), followed by Schmidt, *Supplementum* 140 n. 2.

⁶⁰ Laur. Ashb. 1525, ff. 4^{r-v}. The access to Pinelli's manuscript, which Baldi consulted in Padua, allowed him to clean up a number of mistakes in his first translation (Ambr. D 332 inf., f. 107^r). The only example known to me is Baldi's rendering (34^r) of XXII.4 [72.6], 'si vedevano le navi condotte al mare **sui carretti**' (reading ὁχαίων in place of Ἀχαίων), which he later (Laur. Ashb. 1525, f. 44^r) was able to correct to 'vedendosi le navi **da Grechi** al mare condotte' (cited from Micheli 2005: 251 n. 18). D'Auria (f. 232^r), too, has the erroneous version: 'Naves enim videbantur **a curribus** deductae'. See further below, n. 63.

⁶¹ See, respectively, Affò (1783: 169) and Martin (1854: 40), who refers to the 1661 translation as an unaltered re-edition of the first translation. Despite my best efforts, I have been unable to locate these posthumous translations.

⁶² I agree with Micheli (2005: 251-2) on this point.

[24.16-20]). Some of his translations suggest that his exemplar was a manuscript belonging to what Schmidt considered to be the inferior branch of the tradition (below, §3.2),⁶³ and, in particular, a manuscript somewhat allied to **M**.⁶⁴

The second half of the sixteenth century saw the appearance of at least another translation into vernacular Italian (*Delle cose che si muovono. In volgare*, Ambrosianus N 237 sup., ff. 56^r-78^v),⁶⁵ but the next milestone in the attempts to make the text more accessible to a larger audience is the Latin translation by Couture, Professor at the Collège de la Marche and member of the Académie des inscriptions since 1701. Couture's translation is not particularly noteworthy except for the fact that it is highly dependent on Baldi's. While it is true that Couture shows a certain (admittedly low) degree of independence, as already noted by Schmidt, *Supplementum* 138, he does not improve the places where he deviates from Baldi (there are several mistranslations/misconstructions

⁶³ See already Schmidt, *Supplementum* 141, who supported his view by citing Baldi's translation (40^r) of XXVIII.1 [100.9-10]: 'si vederanno le navi, secondo che s'è detto' (his exemplar probably had φαίνονται in place of οὐ φαίνονται, as in **M**). The Teubner editor (*Supplementum* 140-1) was inclined to accept Prou's suggestion (214 n. d) that Baldi's exemplar was the same as that used by D'Auria (on which, see above, n. 55; more precisely, Schmidt suggested that the only plausible candidate is **Vb**, a manuscript which I have not been able to consult). Prou explained the shared error of Baldi's and D'Auria's translations of XXII.4 [72.6] (above, n. 60) as owing to the corruption of ὑπὸ τῶν Ἀχαιῶν into ὑπὸ (or ἐπὶ) τῶν ἀμαζῶν. This corruption, however, is utterly implausible on palaeographical grounds. Both translators seem to have corrected ὀχάϊων (not ὀχάϊων, as with Micheli 2005: 251 n. 18), which appears in **M** and other manuscripts, to ὀχέων (ὀχέων < ὀχάϊων < ἄχαιων). The reading presupposed by their translations does not seem enough to posit a common exemplar. More recently, Micheli (2005: 251 n. 18) has argued that Baldi based his translation on **Ab**, a manuscript which he unwarrantedly believes to have belonged to Pinelli. But, as Micheli (2005: 248-9) himself acknowledges, Baldi's first exemplar rather belonged to Commandino; see above.

⁶⁴ In addition to the passages cited above (n. 63), see the following translations (the readings given in brackets occur in **M**): 'accomodata di maniera' (18^r: ἁρμοστὴ ὥς, II.8 [12.6]); 'ritornerassi' (20^r: ἀναχωρήσει, IV.3 [18.20-21]); 'r' (21^r: ῥ, VI.4 [26.4]); 'che si vede' (23^v: οὐ λεληθότος, IX.5 [32.11]); 'una' (24^r: αὐτὸ, X.3 [34.14-15]); 'al tutto' (24^r: πᾶσιν, X.4 [34.20]); 'simile' (25^v: ὅμοιος, XI.10 [40.19]); 'che basti' (30^r: μὲν ἐξάρχειν, XVII.2 [58.1]); 'di corna de' cervi' (34^v: ἐξ ἐλαφῶν κεράτων, XXIV.1 [80.7-8]); 'Restami hora' (41^r: Λοιπὸν δέ ἐστιν ἐμοὶ, XXX.1 [106.4]). Cf. also the following readings cited by Baldi: θερίζοντα (42^v n. 8; I.5 [4.12]); διεφελητῶν/διεφλητῶν (43^r n. 10; II.2 [6.16]); κοκλίων (45^r n. 28; XVIII.3 [60.3]). None of the manuscripts that I have consulted appears to have been Baldi's exemplar because they do not contain the following readings which the scholar claims to have found in the Greek text: διαπελέκτιον (44^r n. 21; X.1 [34.1]); περόνην (46^r[45^r] n. 6; XXV.5 [88.6]); κρόταφον (46^v[45^v] n. 12; XXVI.7 [96.2]); σάκωμα (47^v n. 20; XXIX.2 [104.22]).

⁶⁵ Unfortunately, I have not been able to consult this translation, which, according to Micheli (2005: 249 n. 15), covers only BOOK ONE. The manuscript (whose date is 1551-1600) also contains an Italian translation (presumably by the same hand) of Hero's *Pneumatica* (*Degli effetti dei venti. In volgare*, ff. 1^r-50^r).

and a few independent omissions scattered throughout, which seem to stem from a hasty reading of the text). For the most part, he pays very little or no attention to the Greek, as is apparent from the number of calques and omissions that he shares with Baldi.⁶⁶

It was not until 1881 that the treatise was (partly) retranslated into a Western language. Prou's translation into French is fluent and easily readable but is based on an inadequately constituted text. Although Prou pays some attention to technical terminology, his translation often lacks accuracy and precision. His tendency to translate freely becomes most obvious in cases where he relegates the correct translation to a footnote. Contrast, for example, his translation of XXVI.2 [90.16-17] καταδεδεμένοι [sc. αἱ γωνίαι] as 'munis de cordons' (230) with the following explanation (230 n. b): '*reliés par le bas, au moyen d'un cordon sans fin, entourant extérieurement le pied carré de chaque barreau vertical*'. Or, to take a more extreme case, in a footnote he translates the term γομφωτήρια (XXVII.1 [98.5]) as 'tenons de menuiserie' (236 n. c), but in the body of the text, apparently in order to avoid supplying the term of comparison, he opts for its opposite ('mortaises des menuiserie', 236). Some of his renderings are more paraphrases than translations (see, for example, his rendering of XXIV.2 [80.12-13]: 'Les outils seront également de couleur naturelle', 216-17), while others are blatantly wrong (see, for example, his rendering of XXX.7 [110.12-13]: 'La translation des personnages, aussi bien que leurs gestes secondaires'). For a more serious misunderstanding, cf. his Greek text and translation of XXIII.5 [76.16-18]: ὅταν δὲ τὰναντία ἐπιστρέφω τὸν ἄξονα, καὶ μέντοι ἀνοιχθήσονται (ἀνεθήσονται plerique codd.), ὅθεν κλεισθήσονται αἱ θύραι ('si je fais tourner l'arbre en sense inverse, pendant que la porte est ouverte, celle-ci sera refermée', 223).⁶⁷

⁶⁶ Calques and shared omissions occurring in Couture's translation of BOOK ONE, too many to list here, are cited where appropriate in the Commentary. The following list gives examples of (a) calques and (b) shared omissions in Couture's translation of BOOK TWO (as far as (a) is concerned, Baldi's translations appear first, followed by Couture's): (a) XXVI.7 [94.20] 'sia un naspo'(38^v)/'sit modiolus' (270), XXX.2 [106.12] 'ornamenti da capo delle donne' (41^r)/'ad capitis ornamentum mulieres' (273) and [106.14] 'giovanello'(41^r)/'adolescentem' (273), XXX.6 [110.1] 'se altra cosa gli si vede vicina'(41^v)/'si quid aliud in propinquo videbatur' (274); (b) XXIII.5 [76.17] καὶ μέντοι... ὅθεν, XXX.6 [110.2-3] τὸ ὅμοιον.

⁶⁷ See also the criticisms in Schmidt, *Supplementum* 139.

The first complete modern translation appeared as part of Schmidt's edition. His is a rather sophisticated translation and one which privileges stylistic concerns and accessibility (so to speak) over strict faithfulness to the text. His translated text often does not reflect his Greek text, introducing conjectures and/or supplements (whether his own or someone else's) which are otherwise relegated to the apparatus criticus. Sometimes he alerts the reader to the phenomenon, but other times he does not (in his translation he generally uses square brackets to indicate deletions but refrains from using angle brackets to enclose additions). The most conspicuous example of such discrepancies is his rendering of XXVI.4 [92.15-17], where he (435) does not fail to include his tentative emendation <δεῖ δὲ τὸ τοῦ πίνακος ἔδαφος μόνον ἕως τῶν ὀθονίων τῶν συνειλημένων τοῦ χάρτου, ὅταν τῷ κανόνι ἐγγίσῃ> πεπληρωκέναι σε (in place of τε): 'Es ist aber notwendig, wenn man die Wandeldekoration der Achse wirklich nahe gebracht hat, dass man die Fläche der Bühnenhinterwand nur bis zu den Prospektrollen gefüllt hat' (in his note ad loc. he signals his intervention but stresses that the whole of XXVI.4 [92.14-17], which he deletes as spurious, is suspicious).⁶⁸ There are also terminological inaccuracies and misinterpretations (or not so stringent interpretations). For examples of the former, see Comm. on III.1 [14.18-19] and XIII.3 [46.4-6]; for examples of the latter, see Comm. on III.2 [16.7-10], XI.10 [40.19-42.1] and XVII.2 [56.22-58.1].

It was only after more than ninety years that the treatise received a translation into English. Murphy's 1995 translation, which comes accompanied by a brief introduction, bidimensional illustrations and textual and explanatory endnotes, is generally of very poor quality. In her introduction, Murphy discusses (albeit sketchily) several aspects of the text, provides a rapid and

⁶⁸ Examples of this phenomenon in Schmidt's translation of BOOK ONE will be found in the Commentary. For further examples pertaining to BOOK TWO, cf. Schmidt 411 (suggested transposition of πάλιν, XXI [68.10-11]; unclaimed), 415 (Diels' addition of <ἡ δὲ Ἀθηνᾶ ἐπὶ>, XXII.6 [72.20]; claimed), 435 (Schmidt's suggested addition of <τὴν μὲν> or Prou's addition of <ἄλλην μὲν>, XXVI.5 [94.6]; unclaimed), 439 (no fewer than seven emendations, of which six are claimed and one unclaimed, XXVI.7-9 [94.19-96.13]), 443 (Schmidt's suggested addition of <ἐμπεπεγυῖαν>, XXVII.2 [98.10]; claimed), 445 (Schmidt's suggested emendation ἐπιφόρεται or R. Schöne's conjecture ἐπιχρίεται, XXVIII.3 [102.1]; unclaimed) and 453 (Schmidt's suggested addition of <τοῖς μύθοις>, XXX.7 [110.15]; unclaimed but enclosed in parentheses).

incomplete survey of previous scholarship on the treatise and its author,⁶⁹ and partly explains her principles of translation. These principles can be summarised as follows (Murphy 8): (1) the translation is mostly based on Schmidt's text, although some reference is made to Prou's edition of BOOK TWO; (2) some of Schmidt's emendations are adopted for the purpose of improving the legibility of difficult or corrupt passages, whereas some of his lacunae are ignored when the text is deemed translatable without recourse to emendation; (3) occasional departures from Schmidt's textual choices and assessments are duly indicated in the endnotes.

There are several problems with the application of principles (2) and (3) and with Murphy's translation more generally. First, Murphy has a poor grasp of Greek grammar and syntax, which results in frequent mistranslations, misinterpretations and/or unwarranted interpretations. Murphy seems to have a peculiar notion of how to deal with corrupt or lacunose passages, and while she usually uses angle brackets to enclose additions, she also uses square brackets for the same purpose (Murphy otherwise uses square brackets to indicate deletions). This is perhaps best exemplified by her translation of VI.2 [24.12-15] ἀλλὰ μηρυμάτιον ποιήσαντες καὶ προσκολλήσαντες {ἐπειλήσομεν} ἐπὶ τὴν ἐξελίκτην καὶ πάλιν τὰ ἐναντία ἐπειλήσαντες ἀποδώσομεν εἰς τὴν λείαν: 'take stretches of it [*sc.* the cord], glue them on to the cylinder and then wind the [remaining] cord in the opposite direction and attach it to the counterweight' (15-17). Terminological choices aside, it is unclear what the reader should make of '[remaining]' and whether it is intended to correspond to {ἐπειλήσομεν}, which is enclosed in square brackets in Schmidt's text. Take also, for instance, her rendering of XIII.4 [46.11-13], which contains a lacuna (ἐκ δὲ τοῦ $\overline{\Xi\Omega}$ ἀγγείου <***> ἕτερος σωλὴν ὁ $\overline{\chi\psi\omega\varsigma}$ καὶ φέρων ὁμοίως εἰς τὸν $\overline{\upsilon\phi}$ σωλῆνα): 'and from the container $\overline{\Xi\Omega}$, another pipe $\overline{\chi\psi\omega\varsigma}$, likewise bearing towards cylinder $\overline{\Upsilon\Phi}$ ' (23) Here the subject σωλὴν seems to be treated as the direct object of the main verb of the immediately preceding sentence, κείσθω, which is freely translated as 'put'. Second, Murphy only very rarely takes note of the (admittedly many) instances in which she departs from Schmidt's text, and, even when she does, misreadings may be involved (see Comm. on III.2 [16.7-10]). In

⁶⁹ The most notable omissions are Olivieri (1901) and Schmidt (1903); Weil (1882) is cited once, but has been taken into account only marginally and superficially.

all other cases, it is not always clear whether she emends the text in a different way (but see the caveat in Murphy 8), whether she in fact follows Schmidt's (or Prou's) translation, whether she translates creatively or whether she understands the Greek text correctly. One example will suffice. Her translation of XX.2 [64.19-66.2] runs as follows (28): 'as though drawn up [sc. the figure of Athena] by means of a cord, it can appear, upright, and then be hidden again as though drawn down by another cord' (ὥσπερ ὑπὸ σπάρτου τινὸς ἐπισπασαμένης ὀρθὸν φανῆναι καὶ πάλιν ὑπὸ ἑτέρας κατακλιθῆναι). There is no such parallel structure ('as though... as though') in the Greek, and it is difficult to see how 'drawn up' could correspond to ἐπισπασαμένης, which cannot but refer to the cord (σπάρτου τινός). If the verb were meant to refer to Athena's figure (ζῳδῖον), it would have been ἐπισπασαμένου (gender switch should here be ruled out because 'upright', ὀρθόν, still agrees with ζῳδῖον). Third, Murphy has a contradictory approach to interpolations, and while she generally follows Schmidt in deleting passages as interpolated, she treats (or appears to treat) some of these passages as authentic (XI.7 and XI.10, on which see synopsis on XI; for equally unfortunate results, see Comm. on XVI.2 [54.17-18]). Her translation is also not free from omissions (in BOOK TWO alone, for example, she omits translating the whole of XXVIII.7 [104.9-13] ἐπιστρέψει...ε), (terminological) inconsistencies and errors (note especially that she has section XVIII.4 start with XVIII.3 [60.3] καὶ τὰς ἄλλας, etc.). On the whole, Murphy has produced a translation that is certainly more accessible than Schmidt's (at least to readers who may not know German) but which lacks coherence and is misleading or confusing. Murphy's illustrations are rudimentary, not always faithful to the text and occasionally without letter labels; despite her claim to the contrary (Murphy 8), additional elements not mentioned in the text are inconsistently indicated in the endotes or in the illustrations themselves. For reasons that she leaves unspecified, she did not see the manuscript diagrams.

A number of partial translations also exist, scattered throughout various books, theses, and articles. Let me single out only McCourt (2012), who offers not always accurate English translations of III.1 [14.17-16.4], V.3-5 [20.18-22.20], VI.1-2 [22.21-24.9], VII.1-VIII.2 [26.6-28.19], IX.1-3 [28.4-30.2], X.3 [34.12-13], XI.1-4 [36.1-28]. My debt to previous translations is clearly seen in the Commentary.

2.3 The present edition

The overview offered so far shows that previous attempts to edit and translate the treatise have been unsatisfactory to a greater or lesser degree. Until now, one major drawback was the absence of a comprehensive edition and commentary, an absence more acutely felt in recent years in response to the growing scholarly interest in ancient science and technology more generally and in Hero and his works more specifically. The present edition aims at partially filling this gap by offering the first-ever full-scale commentary on BOOK ONE, alongside a re-examination of the manuscript tradition and a systematic, consistent and accurate translation of the entire treatise based on a completely new text. The following aspects of this doctoral study should be particularly noted: (1) the edition depends on a larger manuscript-base than the edition of Schmidt, and alphabetical sigla have been consistently assigned to all manuscripts; (2) the *constitutio textus* and concomitant interpretation have taken into account, in addition to those emendations and editorial interventions already found in Schmidt's edition, the contributions by Weil (1882), Olivieri (1901) and Schmidt (1903); (3) a more balanced approach has been adopted with regard to interpolations, and careful attention has been devoted to the nature and status of the text; (4) the oldest manuscript diagrams have been consulted and included in the study, and a whole new set of reconstructions accompanies the thesis (**Appendix 4**); (5) in order to facilitate comparison between pre- and post-Schmidt editions (where chh. XXII-XXV are arranged in different orders), a concordance of editions has been appended (**Appendix 1**). For an explanation of the principles and criteria followed in the present edition, see below, §6.

3. THE HISTORY OF THE TEXT OF THE *AUTOMATA*⁷⁰

On the basis of current evidence, the text of the *Automata* has been transmitted by 43 manuscripts either in its entirety or in part. Schmidt knew only of 38.⁷¹ The earliest manuscript dates to the thirteenth century: **A** (Marcianus gr. Z. 516, ff. 196^v-208^r),⁷² which Schmidt selected as *codex optimus*. All the other manuscripts are *recentiores*, dating from the fifteenth to the eighteenth centuries. The other three manuscripts upon which Schmidt mainly based his text all date from the sixteenth century. These are **G** (Gudianus gr. 19, ff. 1^r-20^v),⁷³ **M** (Magliabechianus II.III.36, ff. 125^r-141^v) and **T** (Taurinensis B.V.20, ff. 82^v-101^v), the last of which, having been heavily damaged by fire in 1904, now contains only portions of lines 2.1-66.6 (ff. 102^r-114^r are completely lost).⁷⁴

In what follows, I shall first discuss Schmidt's method of listing manuscripts and then provide an updated list, which includes those witnesses to the text that were unknown to him (**Ba**, **Bd**, **Mb**).⁷⁵ This will also allow me to provide information on my use of the manuscripts. I shall proceed to give a summary of Schmidt's account of the tradition. This will lead to an examination of the relationships between the manuscripts. Finally, I shall offer conclusions and future lines of enquiry into the transmission of this text.

⁷⁰ For reasons of space, and for the sake of legibility, the vast majority of references in this section to individual readings and portions of text cite page and line numbers only.

⁷¹ Schmidt, *Supplementum* 56 n. 1 cites Montfaucon's (1739: 677) reference to three more manuscripts of the work, once in the possession of I. Voss in York (numbered 2256, 2312 and 2323). He suggested that since he knew of four Vossian manuscripts in Leiden, two of which contained the *Automata* (i.e. **Lc** and **Ld**), Montfaucon might have simply made a mistake. Another possibility is that the manuscripts were already lost in Schmidt's time. I have been unable to trace these three manuscripts.

⁷² I follow Schmidt's dating of the manuscript, which was confirmed through personal communication with D. Riccoboni. Scholars before him had argued for a twelfth-century date (Zanetti-Bongiovanni 1740: 278) or even a fourteenth- or fifteenth-century date (Haase); see Schmidt, *Supplementum* 3 with n. 4.

⁷³ The last folio of the manuscript (f. 21) is erroneously indicated as 18 in Schmidt, *Supplementum* 7.

⁷⁴ F. Porticelli, special collections librarian, Biblioteca Nazionale Universitaria di Torino, personal communication, June 30, 2015.

⁷⁵ To these should be added **Ha** and **Hb**. Although Schmidt, *Supplementum* 10 knew of the existence of these manuscripts, he was not aware of the fact that, in addition to the *Pneumatica*, they both transmit the *Automata*.

3.1 List of manuscripts

Before listing the manuscripts, it is important to note that the treatise has come down to us under three different titles: *Περὶ αὐτοματοποιητικῆς* (the oldest attested form), *Περὶ αὐτοματοποιητικῶν* and *Περὶ τῶν αὐτοματοποιητικῶν*. (In my view, none of these is the original title, which I have reconstructed as *Περὶ αὐτομάτων*, see my detailed discussion below, §4.) Schmidt, *Supplementum* 54-6 classified the manuscripts in three main categories according to the presence, absence and form of the title, citing separately those whose title was unknown to him (in his list manuscripts are numbered continuously 1-38,⁷⁶ followed by number 39, which corresponds to D'Auria's Latin translation). Schmidt's list is no longer satisfactory for at least three reasons. First, as will become clear below, the form of the title is not necessarily suggestive of a distinct branch of the tradition. Second, Schmidt lumped together manuscripts bearing the title *Περὶ αὐτοματοποιητικῶν* and manuscripts bearing the title *Περὶ τῶν αὐτοματοποιητικῶν* when in fact the latter form is a corruption of the former. Third, his fourth and last group of manuscripts (nos. 33-8) includes manuscripts whose title either was already known in his time (nos. 36-7) or is no longer unknown (nos. 33-4). The list below gives (in alphanumerical order) the name and date of each manuscript, and, when known, the folios containing the text or portion thereof (square-bracketed numbers refer to errors made by Schmidt in the respective descriptions of the manuscripts,⁷⁷ whereas angle-bracketed numbers and/or letters to information he did not provide). The following superscript signs when appearing over manuscript sigla are used to indicate, if known and applicable, the presence or absence of the (different forms of) the title: * = *Περὶ αὐτοματοποιητικῆς*, ** = *Περὶ αὐτοματοποιητικῶν*, *** = *Περὶ τῶν αὐτοματοποιητικῶν*, [∅] = no title. A superscript [?] indicates that the title is unknown.

⁷⁶ Although I do not follow this system, in my list I have included Schmidt's numbers within square brackets to enable the reader to compare my discussion of the tradition with his earlier discussion. Note, however, that although Schmidt also adopted his numbering system for **A**, **G**, **M** and **T**, these are consistently referred to by sigla throughout his discussion.

⁷⁷ Because most manuscripts of the *Automata* also contain the *Pneumatica*, the vast majority of such descriptions are scattered throughout the first chapter of Schmidt's *Supplementum* ("Der Handschriftliche Bestand der Pneumatik", esp. pp. 1-39), where he adopts a different numbering system. This can easily create confusion for the modern reader.

- Ambrosianus C 266 inf., saec. XVI, ff. 331^v-349^r = **Aa*** [1]
- Ambrosianus D 131 inf., saec. XVI, <ff. 1^r-28^r> = **Ab***** [16]
- Amstelodamensis III.F.26 (olim 104), saec. XVII, <ff. 1^r-28^r> = **Ac***** [33]
- Angelicanus gr. 109 (olim S.I.17), saec. XVI (1548–1553), ff. 49^r-67^r = **Ad**** [17]
- Argenteratensis C.III.6, saec. XVI, ff. 167^v-193^v = (**Ae**)* [2]⁷⁸
- Barberinianus gr. 69, saec. XVI-XVII, f. 6^r (only 64.2-14 up to ἀθηνᾶν) = **Ba**
- Barberinianus gr. 261 (olim II.82), saec. XVI, ff. 44^r-66^v = **Bb**** [18]
- Baroccianus gr. 169, saec. XV (1476–1500), ff. 194^v-212^{<v>} = **Bc*** [3]
- Burneianus gr. 108, saec. XVI^{1/4}, ff. 81^v-100^r = **Bd***
- Escorialensis T.I.3, saec. XVI, <ff. 51^r-69^v> = **Ea**** [19]
- Escorialensis Φ.I.10, saec. XVI, ff. 50^{<v>}-<70^r> = **Eb**** [20]
- Fabritius 93 kvart (olim Hauniensis universalis 93), saec. XVIII, <ff. 1^r-15^v> = **F*** [5]
- Gudianus gr. 19, saec. XVI, ff. 1^r-20^v = **G*** [4]
- Harleianus 5589, saec. XVI^{3/4}, ff. 19^r-27^r = **Ha****
- Harleianus 5605, saec. XVI^{2-3/4}, ff. 50^v-69^r = **Hb****
- Leidensis Bonaventurae Vulcanii 4, saec. XVI/XVII (1500–1600?), ff. 35^{<r>}-44^{<v>} (up to 32.18 ἐροῦμεν) = **La***** [21]
- Leidensis Scaligeri 45, saec. XV ex./XVI¹, ff. 64^v-96^v = **Lb**∅ [32]
- Leidensis Vossianus Miscellanaeus 6, saec. XVII, ff. 35^{<r>}-39^{<v>} (up to 32.18 ἐροῦμεν) = **Lc***** [22]
- Leidensis Vossianus Miscellanaeus 17, saec. XVII, ff. 11^r[10]-36^{<r>} = **Ld***** [23]
- Magliabechianus II.III.36, saec. XVI, ff. 125^r-141^v = **M**** [24]
- Marcianus XXX.4 (Class. 11), saec. XVI/XVII = **Ma**? [35]
- Marcianus gr. Z. 516, saec. XIII, ff. 196^v-208^r = **A*** [6]
- Matritensis 4788 saec. XVI, ff. 52^r-71^v = **Mb****
- Monacensis gr. 431, saec. XVI, ff. 17^r-36^r = **Mc*** [7]
- Monacensis gr. 577, saec. XVII, ff. 1^r-11^v = **Md*** [8]

⁷⁸ According to Schöne (1891: 73 n. 2), this manuscript, which was still available to Haase (see above, §2.1), was lost before the time of his writing. Unfortunately, I have been unable to trace the manuscript. I have used round brackets to indicate that the manuscript is lost.

- Oxoniensis Collegii Beatae Mariae Magdalenae 12, saec. XVI (1569–1570), ff. 15^v-33^v[34] = **O*** [9]
- Parisinus gr. 2428, saec. XVI, ff. 52^{<r>}-71^v[73] = **Pa**** [25]
- Parisinus gr. 2430, saec. XVI/XVII (1590–1610), ff. 143^{<r>}-168^v[170] = **Pb*** [10]
- Parisinus gr. 2431, saec. XVI (1540–1550), <ff. 52^v-72^v> = **Pc*** [11]
- Parisinus gr. 2432, saec. XVI (1555–1575), ff. 51^{<r>}-71^{<r>} = **Pd**** [36]
- Parisinus gr. 2434, saec. XVI (1520–1570), ff. 56^{<r>}-90^v[93] = **Pe*** [12]
- Parisinus gr. 2519, saec. XV vel XVI, ff. 1^{<r>}-33^{<r>} = **Pf**** [37]
- Parisinus gr. 2520, saec. XVI, ff. 1^{<r>}-35^v[38] = **Pg****[13]⁷⁹
- Parisinus suppl. gr. 11, saec. XVI, ff. 51^{<r>}-70^{<v>} = **Ph**** [26]
- Philippsianus 1548, saec. XVI (fortasse 1541 vel 1542), ff. 55^v-76^r = **Pi*** [14]
- Riccardianus gr. 47, saec. XVI, ff. 76^v-104^r = **R**** [27]
- Taurinensis B.I.18, saec. XVI, <ff. 36^r-50^v> = **Ta**** [29]
- Taurinensis B.V.20, saec. XVI (1541), ff. 82^v-101^v (now only up to 66.6 εὔρο-μεν) = **T**** [28]
- Thottianus 215, saec. XVI, <ff. 48^r-71^v> = **Tb**** [34]
- Vallicellianus R 29, saec. XVI, ff. 1^{<r>}-25^r = **Va?** [38]
- Vaticanus gr. 1054, saec. XVI, ff. 47^r-66^v = **Vb**** [30]
- Vaticanus Urbinas gr. 75, saec. XVII, ff. 38^r-57^v = **Vc**** [31]
- Vindobonensis suppl. gr. 21, saec. XVII (c.1600), ff. 143^{<r>}-168^{<v>} = **Vd*** [15]

Apart from **A**, **G**, **M** and **T**, Schmidt fully collated manuscripts **La**, **Lb**, **Mc**, **Pi** and **R**. Others he partially collated (**Aa**, **Bb**, **Ma**, **Md**, **Ta**), although the extent of his collations is not always clear.⁸⁰ Additionally, he also relied on the (selective) collations made by Haase ((**Ae**), **Pa**, **Pc**, **Pe**, **Pd**,⁸¹ **Pf**, **Ph**), Hildebrandt (**Vb**) and Prou (**Pa**, **Pb**, **Pe**, **Pd**, **Pf**, **Ph**). On the other hand, he had no access, either direct

⁷⁹ Schmidt, *Supplementum* 54 rightly cites this manuscript as probably having the title *Περὶ αὐτοματοποιητικῆς*. Note that Prou 117 n. 1, who consulted the manuscript, erroneously claims that the manuscripts (known to him) all have the title *Περὶ αὐτοματοποιητικῶν*.

⁸⁰ He collated samples ('Proben') of **Ta**, whereas he inspected **Bb** more extensively ('an mehreren Stellen') than **Aa** and **Ma**. As for **Md**, he only says that it was not fully collated. See Schmidt, *Supplementum* 14, 24, 56, 117.

⁸¹ **Pd** is not mentioned among the manuscripts Haase intended to use for his edition, but Schmidt is explicit that the scholar undertook an extensive collation of the manuscript (*Supplementum* 31).

or indirect, to **Ab, Ac, Ad, Bc, Ea, Eb, F, Lc, Ld, O, Tb, Va, Vc** and **Vd**.⁸² In producing the present edition, I have prioritised the main manuscripts used by Schmidt and those that he did not collate or were unknown to him. Given the scope of this work, I have decided to leave out of consideration **Pi**, which Schmidt convincingly eliminated as apograph of **A** (*Supplementum* 114). I have thus seen manuscripts **La, Lb, Lc, Ld, Pa, Ph, Pg** and **Pf**, and photographic or microfilm reproductions of manuscripts **A, Aa, Ab, Ac, Ad, Ba, Bb, Bc, Ea, Eb, F, G, M, Mb, O, Pb, Pc, Pd, Pe, T, Ta, Tb** and **Vd**. I have also been able to consult images of **Bd, Ha** and **Hb**, but these manuscripts came to my attention too late to be examined and collated for the purposes of the *constitutio textus* and the stemmatic analysis.⁸³ In addition to the lost manuscript (**Ae**), I have been unable to locate **Ma, Mc, Md** and **Va**. For this reason, and because of pressing time and financial constraints, I could not secure access to all manuscripts. I have therefore taken the readings of manuscripts (**Ae**), **Mc** and **R** either from the apparatus criticus or from the *Supplementum* of Schmidt. The same applies to those readings of **T** which are (a) partially preserved or (b) no longer extant. The following list gives all the occurrences of (a) and (b) within 2.1-66.6 (in the former case square brackets enclose portions of text now lost):

(a) [περὶ αὐτομα]τοποιητι[κῶν], 2.2; βάρ[ους], 8.20; πλε[ίον], 8.20; [ἐξ]αρτήσαντες, 10.1-2; κατέστρωται^{av} διακαλύπ[τον]τι, 16.5-6; [ἐ]π[άξει], 18.3; φι[λάσ]σεσθαι, 20.5; ῥ[π], 22.6; περ[ι]τεθεῖσα **T^{mg}**, 24.1; ἀπο[δεμένη] **T¹** : [ἀποδεδόσθω ὁμοίως εἰς] τ[ὴν] λείαν κρίκου συνεχο]μέ[νου] αὐτῇ. πάλιν οὖν κατα[φερομένη] **T^{mg}**, 24.4; [περικ]ειμένην, 26.4; βά[σις], 28.8; λεληθότ[ως], 32.11; κέχρ[ου], 32.12; διαμε[μηρημένα], 34.16; ἐπειλ[ήσεις], 34.21; [καὶ] συμβήσεται, 36.16; ἀποδιῶτα[ι], 60.7; πό[δους], 64.17;

(b) βάρους, 12.1; κατὰ **T²** : μετὰ **T¹**, 22.2; εἰ, 22.21; προωσμὸν, 30.1; ἐκδεθὲν, 32.9; κλειθρίον...πλινθίον **T^{mg}**, 32.14-15; ἦ, 34.7; περιεληφθεῖσα,

⁸² Strangely, his account of the tradition does not include discussion of **Pg**, although the manuscript had in fact been collated by Haase and Prou. Also, he did not mention **Ma, Pd, Pf, Ta** among the manuscripts that were more or less known to him (see *Supplementum* 112 and 115). These discrepancies must probably have depended on the amount of information available to him.

⁸³ These three manuscripts first came to my attention after my primary supervisor learned about them (see Ruffell 2016). Because of the tight timescale for the completion of the thesis, and because other *in situ* collations had yet to be carried out, it was decided to postpone collating **Bd, Ha** and **Hb** until I should be able to revise the thesis for publication (Prof. Costas Panayotakis, personal communication, June 14, 2017).

36.15-16; ἐπιλήσεων, 38.7; ἀρέσκει, 40.6; καὶ, 48.7; σπάρτος om., 48.17; καὶ om., 48.18; τούτου, 50.18; ἐκκρύπτεται, 52.14; περιτίθεται...σπάρτου om. **T¹** : add. **T²**, 54.4; εὖλυτος, 56.1; στεγνότατον, 56.17; ἐξαρχεῖν, 58.1; καὶ om., 58.9; σοῦ, 58.10; τούτη, 58.12; στρέφοντος, 58.18; ἐπειλεῖσαι, 58.21; ἡ om., 60.6; διαπεφραγμένων, 60.12-13; τοῖς, 60.14; ἐκρέει **T^{ac}** : ἐκρέη **T^{pc}**, 60.20; ἐστι, 62.11; κατακεχωρήκαμεν, 64.5-6; βουλόμεθα, 64.7; ἐπιγράφειν, 64.8; καὶ, 64.11; γὰρ, 94.18.

3.2 Schmidt's account of the tradition

Schmidt divides his account of the tradition into three parts. Misleadingly titled "Der Archetypus der *Automaten*", the first part combines discussion of the disruption of the order of chh. XXII-XXV with observations on the archetypal manuscript of the text (*Supplementum* 107-111). He convincingly argues that, because the manuscripts (known to him) have the disrupted chapter order,⁸⁴ they

⁸⁴ All of the complete manuscripts that I have consulted (including **Bd**, **Ha** and **Hb**) have the following textual sequence: XXII.1-6 [70.4-74.3] Οἱ μὲν οὖν... μῦθος + XXIV.1-XXV.1 [80.1-84.11] οὕτως γίνεται... τοὺς τεκτονεύοντας οὕτως + XXII.6 [74.1-3] τῷ πίνακι... μῦθος (with slight variants) + XXII.6-XXIII.8 [74.3-78.19] ἡ μὲν οὖν διάθεσις... διδοῦσα + XXV.1-7 [84.12-90.5] κλεισθέντος... ὅψιν (the correct sequence is henceforth resumed). The disruption is signalled in most manuscripts either with οὐκ ἔστι συνεχὴς ὁ λόγος οὗτος (as in **A** and **G**) or with λείπει (as in **M**), which appear (usually in the margin) where the repetition of XXII.6 [74.1-3] τῷ πίνακι... μῦθος occurs. The *editores principes* (and before them Baldi 46^r n. 5) took the marginal λείπει to indicate a lacuna in the text (printed by Thévenot 266.25-6). Prou 133-7, who recognised the editors' mistake (or, rather, the scribe's mistake), argued that the repeated lines were the result of scribal interpolation (he considered the words τῷ πίνακι as belonging to the beginning of ch. XXV) and filled what he apparently thought was a *different* lacuna as follows: Τὰ μὲν <οὖν> περὶ τοὺς τεκτονεύοντας οὕτως <ἐν> τῷ πίνακι <γίνεται, γενομένης τῆς πρώτης ἀνοίξεως τῶν θυρῶν. Ταύτας δ' ἀμφοτέρως ἀνοιχθείσας δεῖ ἅμα συγκλείεσθαι>, XXV.1 [84.11-12] (Prou 133 n. 45 erroneously states that οὖν is found in **Pb Pd Pg Ph**; the word is nowhere found in the manuscripts). Prou's supplement does not restore the coherence of the text because it leaves the chapter order unaltered (ch. XXIV describes the first scene of the Nauplius play and must follow ch. XXIII, which describes how the doors of the πίναξ are opened and closed automatically). Schmidt's text is based on Schöne's (1891: 74 n. 2) restoration of the original chapter order. Instead, I follow Weil's (1882) reconstruction, which, as we have seen in §2.1 above, was altogether overlooked by Schmidt. The difference between Weil's and Schöne's reconstructions lies in whether or not the words τῷ πίνακι are considered as repeated from the end of ch. XXII. My endorsement of Weil's reconstruction is based on stylistic grounds. The πίναξ is not mentioned in the openings of chh. XXVI (Ταῦτα μὲν οὖν οὕτω γίνεται, 90.6) and XXVII (Ὁ μὲν οὖν παράπλους οὕτω γίνεται, 98.1), which follow the same pattern as XXV.1 [84.11-12]; cf. also XXIV.1 [80.1], where, however, the opening words have been supplied. The omission of τοῦ πίνακος after ἀνοιχθέντος (XXV.1 [84.12]) is easily explained by the very repetition of τῷ πίνακι. Neither Schmidt nor I consulted all available manuscripts, but I find it

all ultimately derive from a single common exemplar ('Exemplar', not 'Archetypus').⁸⁵ Schmidt ascribes such disruption to a transposition of two folios rather than to the combination of said transposition with the replacement of a lost folio with a folio coming from a different manuscript (Schöne's thesis),⁸⁶ and advocates (wrongly in my view) for the archetype as a strongly interpolated manuscript.⁸⁷ The second part, titled "Der kritische Wert von AGT für die *Automaten*", examines the (comparative) value of **A**, **G** and **T**, mainly showing that (1) **A** is the best manuscript, and (2) **AG** belong to a superior class of manuscripts as against **T** (*Supplementum* 111-12). Building upon the analysis of the preceding section, the third part, titled "Beurteilung der übrigen Handschriften der *Automaten*", assesses the rest of the tradition, and includes preliminary consideration of D'Auria's Latin translation (*Supplementum* 112-18). Here Schmidt divides the tradition into two classes of manuscripts. One class consists primarily of manuscripts bearing the title *Περὶ αὐτοματοποιητικῆς* (as in **A** and **G**). To it also belongs **Lb** (where the treatise is untitled). This he regards as the better class ('bessere Klasse'). The other, inferior class ('schlechtere

unlikely that **Ma**, **Va**, **Vb** and **Vc** contain the correct textual sequence. On how the disruption occurred, see below, n. 86.

⁸⁵ See already Schöne (1891: 74 n. 2).

⁸⁶ Schöne's (1891: 74 n. 2) thesis rests on two facts: (1) the repetition of XXII.6 [74.1-3] κεραυνὸς... μῦθος; (2) the lacunose state of XXIV.1 [80.1]. In his view, the lost folio contained XXII.6-XXIV.1 [74.3-80.1] ἡ μὲν οὖν διάθεσις... <Καὶ ταῦτα μὲν> and was replaced by another folio which contained more words at the beginning (κεραυνὸς... μῦθος) and less words at the end (hence the lacuna at the beginning of ch. XXIV). I espouse Schmidt's thesis (*Supplementum* 108-9) that the scribe, after skipping one folio and realising his mistake, signalled the disruption by repeating the lines immediately preceding the end of ch. XXII (which, however, would include τῷ πίνακι, following Weil's reconstruction) and by writing in the margin the words ἔστι συνεχὴς ὁ λόγος οὗτος (which are indeed attested in the oldest manuscript). The textual divergences between the two iterations of XXII.6 [74.1-3] τῷ πίνακι... μῦθος can be explained by assuming that the scribe was citing from memory. Equally, the omission of the initial words of ch. XXIV need not necessarily have occurred at the same time as the disruption, and might represent a later stage of the transmission. Schmidt's thesis makes sense only if we assume that, out of the four folios containing chh. XXII-XXV, the first and the third were rectos: (a') [...] - XXII.6 [74.3] καταστροφὴν εἶχεν ὁ μῦθος, (b') XXII.6-XXIII.8 [74.3-78.19] ἡ μὲν οὖν διάθεσις... διδοῦσα, (c') XXIV.1-XXV.1 [80.1-84.12] <Ταῦτα μὲν οὖν>... τοὺς τεκτονεύοντας οὕτως, (d') XXV.1 [84.12] κλεισθέντος δὲ καὶ [...] (where (b) and (c) have been transposed).

⁸⁷ Schmidt, *Supplementum* 110 bases his argument mainly on the assumption that XI.7 [38.15-40.2], XI.10 [40.17-42.3] and XXVI.4 [92.14-17] are the result of interpolation. I believe that these passages are authentic, and consider the treatise to have been compiled from various sources. See further below, §5.6 (esp. §5.6.1 on snake-like motion). Regardless of the passages in question, Schmidt's appeal to interpolation is logically flawed because extraneous material is much more likely to have been interpolated at a later stage.

Klasse') consists of manuscripts bearing the title *Περὶ αὐτοματοποιητικῶν* (as in **M** and **T**) or *Περὶ τῶν αὐτοματοποιητικῶν*. In addition to these two classes, he identifies three broad groups of manuscripts:

(a) **Aa**, (**Ae**), **Mc** and **Md**, a group closely allied to **G**. **Aa**, **Ae** and **Mc** are shown to be independent of each other, whereas **Md** is considered a copy of **Mc**. **Pb**, which Vincent (1858: 171) was inclined to consider a copy of (**Ae**), closely follows this group (*Supplementum* 112-13);

(b) **Pa**, **R** and presumably **Ta**, a group closely allied to **T**. **Pa** and **R** are dismissed as unimportant in view of this affinity (*Supplementum* 115-16);

(c) **Bb**, **La**, **M**, **Ph** and presumably **Pd** (*Supplementum* 116-17).

Two points are especially striking about Schmidt's evaluation and use of the manuscripts. The first is that he seems to include **M** among the *codices potiores*, although in fact he discusses it together with the other manuscripts (his *consensus codicum a* indeed comprises only **AGT**).⁸⁸ The second point is that he is inclined to regard even those manuscripts of which he has no knowledge as either good or bad, depending on which title they bear (see Schmidt, *Supplementum* 114, 117). I have investigated the manuscript tradition in more detail and have constructed three provisional stemmata based on a partial collation of the manuscripts (**Appendix 3**).⁸⁹ (Note that, in order to avoid incorrect, incomplete or misleading results, my stemma includes neither those manuscripts which Schmidt collated and which I did not collate nor the lost manuscript (**Ae**) nor the extremely fragmentary manuscript **Ba**; for the purposes of the *constitutio textus*, I have undertaken a complete collation of **A**, **G**, **M** and **T**, the last three of which have been consistently cited in the apparatus criticus as representatives of different sub-branches of the tradition.) As I shall demonstrate, my investigation offers some significant corrections to Schmidt's analysis.

⁸⁸ See Schmidt 336 (*Conspectus Notarum*).

⁸⁹ In the stemmata, I use dashed lines to indicate contamination.

3.3 Stemmatic analysis

The manuscript tradition divides into two branches: branch β , represented by manuscripts **A, Aa, Bc, Ea, F, G, Lb, O, Pb, Pc, Pe, Pg, Vd** (**Stemma 1**); and branch γ , represented by manuscripts **Ab, Ac, Ad, Bb, Eb, Ld, M, Mb, Pa, Pd, Pf, Ph, T, Ta, Tb**, and the fragmentary **La, Lc** and **Ba** (**Stemma 2**). The disruption of the order of chh. XXII-XXV suggests that both these branches derive from a common hyparchetype (α) rather than directly from the archetype (Ω), which will have presumably contained the correct sequence of chapters. Manuscripts of the β branch are superior to manuscripts of the γ branch, as is clear, for instance, from the following textual divergences:

- 12.11 τῆς β : καὶ γ (praeter **Ba**)
- 20.16 οὐ β : καὶ γ (praeter **Ba**)
- 20.19 κνώδακι β : κνώδαξι γ (praeter **Ba**)
- 28.15 ὅταν β : οὕτως γ (praeter **Ba**)
- 36.3 ἔτι β : ἔστι vel ἐστὶ vel ἐστὶ vel ἐστι γ (praeter **Ba La Lc**)
- 42.5 ὥς β : ὥστε καὶ ὥς γ (praeter **Ba La Lc**)
- 64.11 τῶν β : καὶ γ (praeter **La Lc**)
- 82.8 τρυπῶ β : τρύπημα γ (praeter **Ba La Lc**)
- 100.12 ἐπιστύλου β : στύλου γ (praeter **Ba La Lc**)
- 102.23 γὰρ β : τὸ γ (praeter **Ba La Lc**)

This bifurcation is further evidenced by a number of omissions that are found in γ but not in β . Take the following examples:

- 4.10 δὲ β : om. γ (praeter **Ba**)
- 28.13 γὰρ β : om. γ (praeter **Ba**)
- 28.20 τῶν¹ β : om. γ (praeter **Ba**)
- 54.13 οὗτος β : om. γ (praeter **Ba La Lc**)
- 58.9 καὶ β : om. γ (praeter **Ba La Lc**)

These two branches are each further subdivided into two main sub-branches, with the β branch leading to **A** and δ , and the γ branch leading to ϵ and ζ . Let us first consider the β branch and then turn to γ .

3.3.1 The β branch

The manuscripts belonging to this branch share only one error in common, namely the omission of 90.6 οὖν. The δ sub-branch contains manuscripts **Aa, Bc, F, G, O, Pb Pc, Pe, Pg, Vd** and cannot stem from **A**, because **A** (and its indirect descendants **Ea** and **Lb**) has a separative error at 22.19 ἀμὸν (ἀν δ).

Schmidt, *Supplementum* 111 rightly regarded **A** as the *codex optimus* because it has comparatively few significant errors and offers good readings not found in the other main manuscripts: 2.9 ἔστι δὲ (ἔστιν **A^{pc}**), 14.14 δ' ἐν (ἐξ οὗ **A^{ac}**), 96.12 μέρος (shared by **ι**). (Of these readings, he cites only 14.14 δ' ἐν and 96.12 μέρος, to which he further adds 20.13 εὐθείας; but here **A** reads ἐπευθείας rather than ἐπ' εὐθείας.)

On the other hand, the vast majority of the δ manuscripts offer a superior text than **A** at 20.20 ἐν τοῖς (ἐντοι **A^{Pe}**) and 24.8 ἀποπορεία (ἀπορεία **F^{ac}**), although they share the former reading with ϵ and the latter with κ . (Schmidt, *Supplementum* 112 cites the former reading among the good readings of **G**; for the disadvantages of his approach, see below.)

δ splits into two further sub-branches (θ and ι), containing, respectively, manuscripts **Aa, Bc, G, F, O, Pb, Vd** and **Pc, Pe, Pg**.

The ι manuscripts share several conjunctive errors, which prove that they form a close-knit group:

2.13 ἀρμόζοντα] ἀρμόζοντι, 10.11 κοινὸν] κοινὰ, 22.2 ἐξελίκτρα] ἐξελίκτραν, 40.3 τοὺς om., 50.3 μέρη om., 66.11 αὐτῷ] αὐτῇ, 90.14 τοῖς om., 108.17 τὸ] καὶ, 110.6 ἦς] ἦς ἔστι.

They share an error found in **A**:

8.8 συνεσμηρισμένας] ἔχων ἐσμηρισμένας (ἔχων εσμηρισμένας **A^{ac}**)

They share two errors found in ζ:

6.16 δι' ἐφηλωτῶν] δι' ἐφηλατῶν

36.13 εἰργασμένοι] εἰργασμένας

Pe and **Pg** cannot derive from **Pc** because **Pc** has the following separate errors against both manuscripts:

2.12 κινεῖται] κεῖται, 20.20 ἐμβεβηκῶς] ἐμβεβηκὰς, 20.20-21 εἰς... τοίχοις om., 100.8 ἡρκῶς] ἡρηκῶς, 100.14 ἄγουσαν] αἴουσαν, 102.9 χάσμα] χάλασμα.

Pc cannot derive from **Pe** and **Pg** because the latter two manuscripts share at least two significant errors not found in **Pc**: 2.17 καὶ] καὶ καὶ, 20.19 ἐν ᾧ] ἐν ᾧ ἐν ᾧ. Cf. also the correct reading of **Pe Pg** at 20.14 ἀποπορεία not found in any other manuscript, including **Pc** (ἀπορείαν). **Pe** cannot have been copied from **Pg** because **Pg** has a separate error at 18.17 ἀναπιτυσμένος (a reading taken from ζ). Similarly, **Pg** cannot have been copied from **Pe** because at 14.12 **Pe** has an error (καὶ νεότερον) which **Pg** could hardly have corrected by conjecture (καὶ νότερον **Pg**). **Pe** and **Pg** thus seem to share a common exemplar (ξ), in its turn derived from ι.

Manuscripts **Aa**, **Bc**, **F**, **O**, **Pb** and **Vd** ultimately derive from a common exemplar with **G**, namely θ, as shown by the following conjunctive errors:

2.6 ἐν] καὶ ἐν, 14.1-2 ὀργάνων... κινουμένων om., 28.23 κειμένου] κινουμένου, 32.17-18 τε καὶ ταπεινοῦσθαι om., 38.13-15 ἡρξάμεθα... χοινικίδι om., 40.6 ἀρέσκει] ἀρέσει, 48.8 οἶνος] ὁ οἶνος, 58.15 ἑτέρα] ἕτερος, 90.2 ἀντιφράσσειν] ἀντιφράσσον, 94.4 ἐναρτῶ] ἐν αὐτῷ, 94.18 κατὰ om., 96.6 ἡζ] εἰζ.

The existence of intermediate exemplars (ν and τ) between θ and **Aa**, **Bc**, **F** and **O** (from which are indirectly derived **Pb** and **Vd**) is supported by two facts. The first is that all these manuscripts (henceforth indicated by ν) share at least two significant errors not found in **G**:

4.13 ἀφύρες ν (σφύραις **Aa^{pc} O^{mg}**) : ἀφύραις **G** (sicut ι)

64.17 γιγκύμω **v** (γιγκύμω **F**) : γιγλύμω **G** (sicut **M^pcsI**)

The second is that **Aa**, **Bc** and **O** (together with its indirect descendants **Pb** and **Vd**) share a number of conjunctive errors not found in **F**:

2.3 αὐτοματοποιητικῆς] αὐτοματικῆς (αὐτοματοποιητικῆς **O^{wp}**), 2.10 προσάγον-
ται] προσαγορεύονται, 42.3 μεσολαβοῦσα] μεσοσυλλαβοῦσα, 54.13 οὖν] δέ,
92.12-14 περιειλεῖν... πίνακος om., 96.1 δέ] δέ καί.

Aa, **Bc** and **O** must therefore derive not from **v** (as **F** seems to do) but from its descendant **τ**. Before looking more closely at the **τ** manuscripts, let us consider **F**. **F**'s scribe seems to have had access to **G** because the manuscript contains errors of **G** not found in the other witnesses: 6.1 δημιουργοῦντας] δημιοῦντας, 32.14 ὀρμήν] ὁ μὴν, 48.10, βάρη] βάρα, 52.20 αὐτόματα] αὐτόματος. Cf. also the following two passages, where **F** reproduces (almost exactly) the readings of **G**:

100.18 ἐπιμήκει κειμένη **F^{mg}** (the main text reads ἐπιμήκει μένη, which shows that the scribe does not realise that **G**'s underlining is meant to correct κειμένη to μένη)

108.10 μέ-|τὸ **G^{ac}** : με- vac. c.3 τὸ **F** (**F**'s underlining draws the reader's attention to the tentative marginal correction μέσον, presumably taken from the **γ** branch)

F also shows signs of cross-contamination from **ψ** (cf. 90.14 ὑπογεγραμμένα) and **ο** (cf. 90.14 ἐν, 106.1 ἀποσπασθείσης, the former also occurring in **Pe^pcsI**).

Aa, **Bc** and **O** form a recognisable subgroup, as shown by the following agreements:

8.9 παρεπιχέειν] περιεπιχέειν, 14.18 τεσσάρων] τετάρων, 16.2 ἐπίκειται] ἐπίκη-
ται, 18.6 ἐκπτυσιθήσεται] ἐκπτυσθήσεται, 48.17 διὰ] διὰ τοῦ.

Aa and **Bc** probably derive from a common sub-hyparchetype (**v**) because they both have at least one significant error not found in **O**: 50.17 γίνεται] καὶ γίνεται (καὶ γίνεται **Aa**). **Bc** cannot derive from **Aa** for chronological reasons, and

because it has the correct text at 28.8 κορυφή (κοίρυφή **Aa O**) and 100.15 ἔπαρ-
 σιν (ἐπάρασιν **Aa O**). Similarly, **Aa** is independent of **Bc** because of the
 following two separative errors of **Bc** against **Aa**: 80.9 μηδὲν] μη δέ, 110.8 καὶ
 καλυφθῆναι] κεκαλυφθῆναι. Manuscripts of this subgroup show signs of
 contamination from the **γ** branch, and perhaps more specifically from **ζ**: cf.
 readings at 4.12 σκερπανίζοντα, 6.15 ἀπωθώσαντες (a further corruption of ἀπο-
 θώσαντες) and 20.12 πεπειρασμένοις (a reading found in **ζ** and also shared by
Bb Ea Lb Tb). Cross-contamination is also likely to have occurred between **Aa**
 and, respectively, **o** and **Ph**: for the former relationship, cf. 42.2 τούτον (**Aa^{pchl}** :
 τοῦτον **o**) and 48.17 σπάρτος (a reading tentatively added by **Aa^{mg}** and which in
 all probability was already found in **κ**); for the latter, cf. 106.12 ἄμπυκας (**Aa**
Ph (dub. in mg.)).

O, **Pb** and **Vd** share the following errors against **Aa** and **Bc**:

20.9 ἀποπορεία] ἐμπορείας (ἐκπορείας **Pb^{ac}**), 46.2-3 τὰ δὲ... ζῆ² om., 94.8-9 τὸν
 ἐν... κανόνα om., 98.9-11 ἐν ᾧ... δελφιναρίου om.

Pb and **Vd** share numerous conjunctive errors not found in **O**, for instance:

4.6 θυρῶν] ρυτῶν, 22.2 ἡ μὲν] ἡμῖν, 50.21 κλειθρίον] κλειτριόν, 52.20 αὐτόματα
 τὰ] τὰ αὐτόματα, 58.5-6 πάχος... ἄξονος om., 66.4 βροντῆς] φροντῆς, 80.8 μάλα
 κατειργασμένας] μάλακα τειργασμένας, 108.18 τὰ κύματα] τὰ κύματα καὶ κύ-
 ματα.

Pb cannot derive from **Vd** because **Vd** has omissions not found in **Pb**: 22.1 ἴσοι,
 30.19-22 πορευθῆναι... πλευρὰν (πορευθῆναι om. **Pb**), 66.21-22 ἀναγεγραμμέ-
 νων... αὐτοῦ (omitted also by **Bb Ta**, probably through contamination), 106.4
 ἡμῖν. Likewise, **Vd** is unlikely to have been copied from **Pb** because **Vd** does not
 reproduce the text of 42.5-7 as it appears in **Pb**: ὡς ἐὰν προαιρώμεθα διαμεμηρυ-
 μένα, ὡς εἴρηται, καὶ ἡ τοῦ πλινθίου] ὡς εἴρηται, καὶ ἡ τοῦ πλινθίου ἐὰν προαι-
 ρώμεθα διαμεμηρυμένα ὡς εἴρηται καὶ ἡ τοῦ πλινθίου. **Pb** and **Vd**, therefore,
 seem to be close copies of an exemplar (**ω**) derived from **O**.

The **θ** manuscripts present a superior text than **A** at 6.19 ὑπάρχη, 40.19
 ἕτερος, 106.7 ἔδαφος, 106.13 θωράκιον, 108.13 περόνιον, although some of

these readings are shared either by ϵ (106.7, 106.13), by η (6.19) or by both (108.13). (Schmidt, *Supplementum* 112 cites 40.19, 106.7 and 106.13 among the good readings of **G** but he clearly overlooks the connections between **G** and manuscripts of the ϵ branch, in particular **M**.) **G** is superior to the other manuscripts of this family (including the earlier manuscript **Bc**) because, as the lists above have shown, they contain a number of additional errors not found in **G**. **G** has a better reading not found in **A**, **M** and **T** at 108.17 τούτω (shared also by **Aa Ac Ld Ta**).

Finally, before moving on to consider the γ branch, let us look at **Ea** and **Lb**. These two manuscripts (the former of which transmits the text under the title *Περὶ αὐτοματοποιητικῶν*, whereas the latter has no title) share some errors of **A** not found in the other manuscripts. In addition to 22.19 ἄμὸν (see above), cf. the following (minor) errors: 20.2 γὰρ γενηθέντων] γὰρ γε γενηθέντων (in **A** two letters have been erased after γε, perhaps νν, as suggested by comparison with γεν- in γενηθέντων), 36.15-16 περιειληθεῖσα] περιειληθήσα, 62.6 ὑπὲρ τροχῶν] ὑπερτρόχων (here **T** now reads [***]όχων, although the agreement of **Eb Pa Ta** gives us what is in all probability the original reading, ὑπὲρ τρόχων; **Pf**'s corrupt reading ὑπὲρ τρόπων, too, supports both the word-division and the accentuation). **Ea** and **Lb** also share numerous conjunctive errors that prove that they are gemelli. Some examples:

2.19-20 διεσκευασμένων] διεπισκευασμένων, 6.11 ἐμποδίζονται] ἐμποδιζόντων, 10.4 δεῖ χρησθαι] χρησθαι δεῖ, 20.13 πορείαν] πυρίαν, 20.19 πλινθίον] πλινθίδιον, 58.18 ἅπαξ στρέφοντος] ἅποστραφέντος, 66.5 πολλοῖς] πάλιν, 106.5 πεσεῖται] πείσεται, 108.13 ῥίψη] ῥύψει, 110.1-2 προσαπονενέμῃται] προσαπονετεύμῃται.

Both manuscripts share an error found in ϵ :

94.10 ἐζηρημέναι] ἐζητημέναι

They also share some errors found in ζ , for instance:

4.12 πρίζοντα] περίζοντα (περὶ ζόντα **Ea**)

80.14 ἐτρύπησα] ἡτρύπησα

Lb cannot derive from **Ea** because **Ea** has omissions not found in **Lb**: 14.18 τεσσάρων (τετάρων **Lb**), 16.15 τοῦ. **Ea** also has a separative error at 88.2 τρύπημα (a reading taken from ζ; here **Lb** has τρύπνα, an error probably due to a misreading of the exemplar, which in all likelihood will have reproduced the hardly legible reading found in **A**: τρυπᾶν **A^{ac}** : τρυπῶ **A^{pc}** (ut videtur)). On the other hand, I have been unable to find errors peculiar to **Lb** which could exclude the possibility that **Ea** has been copied from **Lb**. The close correspondences between the two manuscripts would suggest that **Ea** is the apograph of **Lb**, but in the absence of a full collation it is difficult to reach definitive conclusions. Regardless, it seems clear that the two manuscripts derive from a descendant of **A** which is now lost and in which the treatise was untitled (η); **Ea** must have taken its title from γ.

3.3.2 The γ branch

The γ branch is more complex than the β branch. Its two sub-branches (ε and ζ) contain, respectively, manuscripts **Ab, Ac, Ad, Bb, La, Lc, Ld, M, Mb, Pd, Ph, Tb** (and apparently also the exiguous fragment of **Ba**) and **Eb, Pa, Pf, T** and **Ta**. The ε manuscripts share errors not found in ζ and vice versa, although there are evident traces of contamination between the two sub-branches:

- 4.1 κεκλεισμένοι ε (praeter **Ba Tb^{pcsl}**) : κεκλεισμένων ζ **Tb^{pcsl}**
- 6.19 ὑπάρχοντι ε (praeter **Ba La^{pc}**) : ὑπάρχων τι (vel τί vel τὶ) ζ (praeter **Ta^{pcsl}**) : ὑπάρχων τί **Ta^{pcsl}** : ὑπάρχων **La^{pc}**
- 10.18 κατὰ ε (praeter **Ba**) : ἐπὶ om. ζ
- 12.10 στατοῖς ε (praeter **Ba**) : στρατοῖς ζ
- 64.3 ἀναγεγράφθαι ε (praeter **La Lc**) : ἀνεστράφθαι ζ (ἀνεστράφ[***] **T**)
- 106.4 ἐμοὶ ε (praeter **Ba La Lc**) : ἡ μὲν ζ

ε splits into two further sub-branches (κ and λ), containing, respectively, manuscripts **Ab, Ac, Bb, La, Lc, Ld** and **Ad, M, Mb, Pd, Ph** and **Tb**. The

following readings shared by some manuscripts of **κ** and **λ** indicate that there has been contamination between the two sub-families:

42.1 τριῶν] ποιῶν vel ποίων **Ad Ab^{mg} Bb Pd**

42.11 κινήσεων] κινήσεως **Bb M Tb**

54.6-7 ἐκδεδεμένα] ἐκδεδομένα **Ab Ac Ad Bb Ld** (ἐκδεδεμένα **Ac^{ac}**)

80.15 ἐποίησα] ἐποίησας **Bb M^{ac}**

96.11 ἐκλυθείσης] ἐκλυθείσης **Ab Ac Ad Ld M Tb**

The **λ** manuscripts share a few conjunctive errors and probably derive, through intermediaries, from a common exemplar. I list the common errors that I have found: 2.11 ὠρισμένους] ὠρισμένα, 10.7 κατατεταγμένος] κατατεταμένος, 92.1 εὐστροφα] εὐστροφαι. The following partial agreements should also be noted:

62.1 ἡλιθρίον **M Tb** : ἡλιθρίον **Ad Pd Ph** : ηλιθρίον **Mb**

72.1-2 τελεύεσιν **M** : τελέκεσιν **Ad Mb** : τελέβεσιν **Pd Ph Tb¹** (πελέκεσιν **Tb^{2mg}**)

104.21 ἐπισπαμένην **Ad M Mb Pd Ph** : ἐπισπασμένην **Tb^{ac}** (ἐπισπασαμένην **Tb^{pcsl}**)

The exact relationship between manuscripts belonging to this group is difficult to establish.⁹⁰ However, it seems possible to make the following suggestions:

(1) **Ad, M, Ph, Tb** seem to ultimately depend on a different sub-hyparchetype (**π**) from **Mb** and **Pd** because they have at least one significant error not found in **Mb** and **Pd**: 64.10 ἀναγεγραμμένων] καὶ ἀναγεγραμμένων. Conversely, **Mb** and **Pd** have a separative error at 96.11 ἐκλυθείσης (cf. above; ἐκθείσης **Ph^{ac}** : ἐκχυθείσης **Ph^{pcsl}**);

(2) **Ad** and **Ph** seem close to each other and perhaps presuppose a common exemplar (**χ**), as suggested by the following conjunctive errors not found in the other manuscripts: 8.2 δυσκίνητα] δυσκίνειτα, 52.14 εὐαρμόστως] εὐαρμόστος, 54.3 μέρους] μέρου, 64.19 ὥστε] ὥσται. **Ph** cannot derive from **Ad** because of the following separative errors of **Ad** against **Ph**: 58.17 τὴν $\bar{\lambda}$ om.,

⁹⁰ According to Prou 132, **Pd** and **Ph** seem to be apographs of **Pa**. This cannot be because **Pd** and **Ph** share no substantial errors with **Pa**.

90.6 κλεισθέντος] λειφθέντος, 96.5 στραφήσεται] στροφήσεται, 110.1 τι om. Similarly, **Ad** cannot derive from **Ph** because of the following separative errors of **Ph** against **Ad**: 66.9 πολλῶν] πολλῶν, 96.7 ἐξελίσσειν] ἐξελλίσσειν. Cf. also above under (1);

(3) **Tb** appears to have a closer relationship to **M** than the other manuscripts of this group, although it generally presents a more corrupt text than **M** and shows signs of contamination (I have called their hypothetical hyparchetype **ψ**). Consider especially the following common omissions of **M** and **Tb** not found in the other manuscripts and which **Tb**² has often filled either above the line or in the margin: 2.17 ἦ (add. **Tb**^{2sl}), 16.2 ἐπίκειται (add. **Tb**^{2mg}), 26.21 ἦ (add. **Tb**^{2sl}), 98.13 ἦ. Cf. also the following errors common to both manuscripts and not found elsewhere: 18.2 τόπον] τρόπον (τόπον **Tb**^{pcsl}), 26.18 οὕτως] ἔτι (οὕτως **Tb**^{2mg}) 90.6 κλεισθέντος] λεισθέντος (κλεισθέντος **M**^{2sl}), 90.14 ὑποπεφραγμένα] ὑπογεγραμμένα. **Tb** appears to have derived some readings from **θ** (for instance 94.4 ἐν αὐτῷ) and from **ζ** (for instance 80.12 ὁμοχόρους, also shared by **Mb**). See also above.

In comparison with other manuscripts belonging to the **ε** branch, **M** more consistently offers good readings not found in **A**, **G** and **T**. Schmidt, *Supplementum* 117 belittlingly calls these ‘leichteren Verbesserung’ and claims (rightly, I believe) that they are due to conjectural emendation. He gives a list of 19 passages but singles out as particularly remarkable only three: 8.3 ἐγκυκλίους (so also **Tb**; the other **ε** manuscripts are variously corrupted), 10.8 ἔσται δῆλον, 94.17 πλοίων (so also **O Ta** and the other **ε** manuscripts except **Bb**, which derives its reading, πλείων, from a different branch). Cf. also especially 6.6 μηδὲν ἐπιζητοῦντα (μηδὲν ἐπιζητόντα **Ac Lc**), 16.11 ἐκπεπετακυῖα (ἐκποπετακυῖα **Ph**) and 100.18 ἐπικειμένη.⁹¹ It is likely that most of these conjectural corrections were already in **ε**.

Manuscripts **Ab**, **Ac**, **La**, **Lc** and **Ld** ultimately derive from a common exemplar with **Bb**, namely **κ**, as shown by the following conjunctive errors:

⁹¹ Schmidt, *Supplementum* 117 strangely cites the first two readings among the conjectural improvements of **La**. His app. crit. to 6.6 [= 342.8 Schmidt], on the other hand, records only **Bb** and **La**.

8.3 δεῖ δὲ καὶ ὅσα] καὶ ὅσα δὲ δεῖ, 10.7 κατατεταγμένος] ἐντεταμένος, 12.11 ἐκ] διὰ, 16.15 παρακαθέζεται] παρακαθίζεται, 14.20 ἐφέστηκε om. (add. **Ac**^{2mg} **Ld**^{2mg}), 20.10-11 κατακολουθοῦντα] ἐπακολουθοῦντα (επα- **Lc**).

There is also little doubt that some errors common to **Ab**, **Ac**, **Bb** and **Ld** and occurring beyond the point in which **La** and **Lc** break off were already found in **κ**: 36.7 ἄξονες] οἱ ἄξονες, 58.14 ἀποδεδέσθω] ἀποδεδόσθω, 64.18 κατακεκλιμένον] κατακεκλισμένον (κατακεκλιμένον **Ac**^{2mg} : κατακεκλημένον **Ld**^{2mg}). Contamination is likely to have occurred at the level of **κ** because all these manuscripts have the same reading (or insignificant variations thereof) as that found in **A**^{ac} (2.9 ἔστι δὲ **Bb La** : ἐστὶ δὲ **Ab** : ἐστὶ δὲ **Ac Ld** : ἐστὶ δε **Lc**).

Manuscripts **Ac**, **La**, **Lc** and **Ld** seem to descend (through various intermediaries) from a common exemplar with **Ab** which was copied from **κ**, namely **ο**. This is suggested not only by the fact that all these manuscripts have the title *Περὶ τῶν αὐτοματοποιητικῶν* but also by the presence of conjunctive errors of **Ab**, **Ac** and **Ld**. The ones that I have found all occur beyond the point in which **La** and **Lc** break off (for the relationships between **La**, **Lc** and **Ld**, see below). Some instances:

92.16-17 πεπληρωκένοι] πεπληρωμένοι, 94.19 ἐλίσσεται] εἰλήσεται (___εἰλήσεται **Ld**), 96.4 ὅπως] οὕτως, 100.14 παράπλουν] τετράπλουν, 104.21 ἐπισπασαμένη] ἐπισπωμένην, 106.1 ἀποσχασθείσης] ἀποσπασθείσης.

Cross-contamination is likely to have occurred at the level of **ο**, too, because **Ab**, **Ac** and **Ld** all share with **β** the omission of 90.6 οὖν (on which, see above). **Ab**, furthermore, seems to have consulted **A** (or, perhaps more likely, its apograph **Pi**) because it shares with **A** the omission of 12.9-10 διὰ... ἐμβάλλεται (add. **A**^{mg} **Ab**^{mg}).

The existence of intermediaries between **ο** and **Ac**, **La**, **Lc** and **Ld** can be inferred from the following considerations.

(1) **Ac**, **La**, **Lc** and **Ld** cannot derive from **Ab** because **Ab** has numerous errors and omissions not found in **Ac**, **La**, **Lc** and **Ld** (or in **Ac** and **Ld** alone when these occur beyond the point in which **La** and **Lc** break off). Some examples: 6.10-11 οἱ τροχοὶ... μήτε om. (add. **Ab**^{mg}), 34.13 καὶ ταπεινωθήσεται

om. (add. **Ab^{mg}**), 58.15 $\overline{\epsilon\zeta}$ $\overline{\epsilon\zeta}$ $\overline{\epsilon\zeta}$. Given the mutual independence of **Ac**, **La**, **Lc** and **Ld** (on which, see points below), the following error common to these manuscripts and not found in **Ab** was already in their common (ultimate) exemplar (**φ**): μίγματι **φ** : πίγματι **Ab^{ac}** : πνίγματι **Ab^{pcsl}** (a reading probably taken from **Bb**). The same applies to some errors common to **Ac** and **Ld** and occurring beyond the point in which **La** and **Lc** break off. One example: 100.6 ἐκσπάσει] ἐκοπάσει.

(2) **La**, **Lc** and **Ld** cannot (partly) derive from **Ac** because **Ac** has the following omissions not found in **La**, **Lc** and **Ld**: 6.12-13 εἰς τὸ ὀπίσω, 30.3-32.3 Ἦ δὲ... οὖν.

(3) **Ac**, **La** and **Lc** cannot (partly) derive from **Ld** because **Ld** has a separative error at 16.5-6 διακαταλύπτοντα (καλύπτοντα **Ld^{2mg}**, a reading taken from **β** and appearing also in **La^{ac} Ta**; **Ac^{2mg}** corrects the reading of other **ε** manuscripts, διακαλύπτοντα, to διακαλύπτοντες). Given the independence of **Ld** from **La** and **Lc** (on which, see point (4) below), it is likely that the following errors common to **La**, **Lc** and **Ld** and not found in **Ac** were already in **Ld**'s direct ancestor (**αα**): 18.17 ἀναπτυσιμὸς] ἀναπιτισιμὸς, 20.18 τι] τὸ, 30.21 αὐτῶν τὴν om.

(4) **Ld** cannot derive from **La** and **Lc** both because the latter two manuscripts are incomplete and because they share the following conjunctive, separative errors against **Ld**:

16.9 κωνοειδὲς om., 20.14 γίνεσθαι] γίνεται (γίγνεσθαι **La^{mg} Ld**), 26.8 διήχθω] διήχω, 28.7-8 τροχοὶ... πρ om.

Lc cannot derive from **La** because **La** has the following separative errors against **Lc**: 2.4 ἡξιωμένης] ἄξιαμένους (ἡξιωμένης **Lc**), 2.17 ὑπόσχεσις] ὑπόστασις, 8.8 συνεσμηρισμένας] συνεπιμεμερισμένας (συνεπιμερισμένας **Lc**, a reading shared by **Ab Ac Bb Ld**). Similarly, **La** does not seem to have been copied from **Lc** because **Lc** has at least one separative error against **La**: 20.10 σπάνιον] οπάνοιν (ὀπάνιον **Lc^{mg}**). It is therefore likely that **La** and **Lc** descended from a common, incomplete exemplar (**ββ**), in its turn derived from **αα**.

Although **Ac** and **Ld** are somewhat removed from one another, they often share the same variant readings and marginal annotations. Some of these are

nothing more than erroneous conjectures, while others are the result of contamination from **β** – or, in some cases, more specifically from **ι**. As an illustration, consider the following agreements:

I.22.13 ἀρμόζοντα **Ac¹ Ld** (in textu) : ἀρμόζοντι **Ac^{2mg} Ld^{mg}** (sicut **ι**, de quo vide supra)

I.54.12 θερίζοντα **Ac¹ Ld** (in textu) (sicut ceteri codices familiae **ε**) : πρίζοντα **Ac^{2mg} Ld^{mg}**

XX.264.7-8 ἐπιγράφειν καινότερον **Ac¹** (~~ἀναγράφειν ante ἐπιγράφειν delete~~) **Ld** (in textu) (sicut ceteri codices familiae **ε**) : al. cod. γράφειν καιν[^{*}]τερον **Ac^{2mg}** : al. cod. γράφειν καινούτερον **Ld^{mg}** (γράφειν καινότερον **β**)

XX.164.8 πρὸ ἡμῶν **Ac¹ Ld** (in textu) (sicut ceteri codices praeter **Ea Pc ξ**) : πρὸς ἡμᾶς **Ac^{2mg} Ld^{mg}** (sicut **Pc** : πρὸς ἡμᾶς **Ea ξ**)

Let us conclude our analysis by turning to **ζ**. Within this family, we can distinguish, on the one hand, between **Pf** and **Ta**, and, on the other, **Eb**, **T** and **Pa**. **Pf** and **Ta** appear to derive directly from **ζ** and to have little independent value when compared with other manuscripts of the same family, especially **T**. This is so for two reasons. First, **Ta** presents a composite text, with readings taken from **β** and **ε**. Examples of the former:

16.5-6 καλύπτοντα **Ta** : διακαλύπτοντι **T** (sicut **Eb Pa Pf**)

66.7 κατατρέχοντας **Ta** (sicut **Bb^{pcsl}**) : κατατρέχοντες **T** (sicut ceteri codices familiae **γ** praeter **Bb^{pcsl}**)

Examples of the latter:

16.11 ἐκπεπετακυῖα **Ta** : ἐκπεπετακοῦσας **T** (sicut **Eb Pa Pf**)

20.21 συμφυεῖς **Ta** (sicut **Pe**) : συμφυῆς **T** (sicut ceteri codices familiarum **β** et **ζ**)

22.1 οἱ **Ta** (sicut **F^{mg}**) : ἡ **T** (sicut ceteri codices familiarum **β** et **ζ** praeter **F^{mg}**)

See also above. Second, **Pf** seems more corrupted than **T** (I will provide some examples below). **Pf** cannot derive from **Ta** for chronological reasons, and because **Ta** has the following errors peculiar to itself: 36.4 καὶ] ὅτι, 96.7 ἐξελίσ-

σειν] ἐξελίξειν (ἐξελίσσειν **Ta^{mg}**), 108.11 περονίῳ] περόνιον. Similarly, **Ta** cannot derive from **Pf** because **Pf** has the following two unique omissions: 24.3-4 ὁμοίως... πάλιν, 100.14-15 τὸν... πραγ-.

Manuscripts **Eb**, **T** and **Pa** share a number of conjunctive errors not found in **Pf** and **Ta**:

8.6 εἰς om. (add. **T^{2mg}**), 10.11 καὶ] τῆς (καὶ **T^{2mg}**), 20.11-12 ἔστι φανερόν] ἐπιφανερὸν (ἐπιφανερὸν **T¹** : ἔστι **T^{2mg}**), 22.2 κατὰ] μετὰ (κατὰ **T^{2mg} Eb^{2mg} Pa^{mg}**), 36.16 συμβήσεται] καὶ συμβήσεται (~~καὶ~~ **T**).

Eb and **Pa**, moreover, share conjunctive errors (presumably) not found in **T**:

4.9 ταύτην] ταύταν, 6.10 ἐν om., 8.1 πειρᾶσθαι] ποιρᾶσθαι (πειρᾶ[*]θαι **T**), 64.8 γράφειν] ἐπιγράφον (ἐπιγράφειν **T**), 66.23 ὠφελείας] ὠσελείας ([***] **T**).

Eb is closer to **T** than **Pa** is, because it reproduces, either exactly or nearly so, some omissions and marginal additions of **T** that **Pa** does not: 24.3-4 -δόσθω... καταφερο- (ἀποδεμένη **T¹ Eb¹** : ἀποδεδόσθω... καταφερομένη add. **T^{2mg} Eb^{2mg}**), 28.11 καὶ (add. **T^{2mg} Eb^{2mg}**), 32.14-15 κλειθρίον... πλινθίον (add. **T^{2mg} Eb^{2mg}**), 54.4 περιτίθεται... σπάρτου (add. **T^{2mg}** : σπάρτου... τῆς add. **Eb^{2mg}**). These dissimilarities between **Eb** and **Pa**, along with the existence of errors of **Eb** not found in **Pa** (for instance 80.14 αὐτὴν] αὐτοῦς), suggest that **Pa** does not derive from **Eb**. Similarly, **Eb** cannot derive from **Pa** because **Pa** has the following separative errors against **Eb**: 6.10 μήτε om., 16.7 ναῖσκος] ανίσκος, 36.21-22 χάλασμα] χάσμα. There is, therefore, enough evidence to suggest that **Eb** and **Pa** are descended from the hyparchetype of **T** (**μ**) through a common intermediary (**σ**).

Finally, note the following agreements between, respectively, (1) **Eb** and **Pf** and (2) **Pa** and **Pf**:

(1)

2.6 συνελόντι] συναλόντι (corr. **Eb^{2sl}**)

(2)

20.13 εὐθείας] ἐπαλὸν θείας (**Pa^{cp}**)

22.3 αὐτὴ] αὐγὴ

3.4 Conclusions and future research

In this section, I have shed new light on the history of the text of the *Automata*. As has been seen, Schmidt divided the manuscript tradition into two branches, within which he identified three rather vague groups of manuscripts. While he was able to eliminate **Md** and **Pi** as apographs, his analysis did not go far enough in examining the relationships between the manuscripts and, in particular, between the main branches of the tradition. My starting point has been Schmidt's classification of the manuscripts. I have focused my attention on updating his classification, on the one hand, and on attempting to establish the relationship between the manuscripts, on the other. My stemmatic analysis has demonstrated three things:

(1) While Schmidt's division into two branches still broadly holds, the manuscript tradition is much more fluid than his account leads us to believe (for cross-contamination, see **Stemma 3**, where, for the sake of simplicity and clarity, I have indicated only the first layers of the main families of manuscripts). Manuscripts belonging to the β branch almost always, but not exclusively, share the title *Περὶ αὐτοματοποιητικῆς*. Although in fact belonging to the β branch, manuscript **Ea** has been shown to have derived its title (*Περὶ αὐτοματοποιητικῶν*) from the γ branch.⁹² Schmidt's criterion for predicting the value of individual witnesses, therefore, is no longer entirely adequate;

(2) Although **G** and **T** occupy a lower position in the stemma when compared to other manuscripts of their families, they are of superior stemmatic value and should therefore be retained as representatives of their branches;

(3) Because **M** offers good readings not found in **A**, **G** and **T** and presents a purer text than **Tb**, it deserves to be included among the main manuscripts. As a result, my *consensus codicum a* differs from that of Schmidt in its inclusion of **M**.

My analysis of the manuscript tradition of the *Automata* shows that there is still much work to be done, and I conclude by suggesting briefly some

⁹² A cursory look at Schmidt's account of the tradition tends to confirm that, among the manuscripts that I have not collated, those bearing the oldest form of the title belong in the β branch (**(Ae)**, **Mc**, **Md**) and those bearing the title *Περὶ αὐτοματοποιητικῶν* belong in the γ branch (**R**, **Vb**, and possibly also **Vc**). Casual inspection suggests that the same holds true, respectively, of **Bd** (β branch) and **Ha** and **Hb** (γ branch).

directions for future research. First, future work should focus on undertaking a full collation of all extant manuscripts. Only when that is done and all manuscripts incorporated into the stemma will it be possible to identify apographs, revise the apparatus criticus and use sigla indicating consensus between groups of manuscripts. Second, considering the nature of the tradition, it would be fruitful to investigate contamination at a more granular level. Such investigation, which will necessarily include closer inspection of *marginalia*, is expected to shed more light on the links between manuscripts. Third, greater attention will need to be devoted to palaeographical and codicological aspects. The primary purpose of such a study will be to provide an updated description of the manuscripts, which will in turn benefit the stemmatic analysis. Fourth, the issue of scribal emendation will have to be examined more closely in order to better assess and compare the value of individual witnesses.

4. TITLES

The discussion in the previous section leads us to the inevitable question: ‘What was the original title of the work?’. The form *Περὶ τῶν αὐτοματοποιητικῶν* should be left out of consideration because, as we have seen, it is a corruption of *Περὶ αὐτοματοποιητικῶν* which appears in an inferior branch of manuscripts. Our choice, then, seems to be between *Περὶ αὐτοματοποιητικῆς* [*sc. τέχνης*] and *Περὶ αὐτοματοποιητικῶν*. The former has been adopted by Schmidt and Murphy,⁹³ while the latter was the only title known to Thévenot (who adopted it) and to Prou⁹⁴ (who emended it; see below, §4.1) and was apparently endorsed by LSJ s.v. αὐτοματοποιητική.⁹⁵ Before starting our discussion, we should bear two

⁹³ Schmidt 339 translates the title freely as ‘Die Automatentheater’, although he also offers two more literal translations: ‘Der Automatenbau’ (339 n. 1) and, keeping closer to the original, ‘die Kunst Automaten zu bauen’ (*Supplementum* 54). Murphy 11 has ‘On Automaton-Making’, and refers to the Greek title either as *Peri automatopoiētikēs* or (quite illogically) as *Automatopoiētikēs*.

⁹⁴ But see above, n. 79.

⁹⁵ Its transliterated nominative form (‘*Automatopoetica*’, LSJ s.v. Hero) has gained favour among classical scholars; see e.g. Mango (1950: 23 n. 42), Sambursky (1962: 177 n. 44), Tarrant (1976: 275), Facal-González (1982: 179), Cuomo (2002: 166 n. 4), Berryman (2007: 44 n. 19), Mitchell (2007: 226) and De Groot (2016: 56). Although LSJ cite the title as τὰ αὐτοματοποιητικά, they are unlikely to refer to the form *Περὶ τῶν αὐτοματοποιητικῶν* (see my remarks in §3.1 above about Schmidt’s listing of the manuscripts).

things in mind. The first is that the various versions of the title attested in the manuscripts include the author's name (usually, Ἡρώωνος Ἀλεξανδρέως)⁹⁶ as their first element. The second is that uncertainty often surrounds the genuineness and reliability of titles of ancient works.⁹⁷

While Schmidt, *Supplementum* 54 found both *Περὶ αὐτοματοποιητικῆς* and *Περὶ αὐτοματοποιητικῶν* plausible,⁹⁸ he preferred the former title on grounds of manuscript support. To corroborate his preference, he made two additional points. First, *Περὶ αὐτοματοποιητικῆς* finds better support in other names of *technai*: βελοποιϊκή (Ph. *Bel.* 51.8; Hero, *Bel.* 74.10), θαυματοποιϊκή (Procl. *in Euc.* 41.8), ὀργανοποιϊκή (Procl. *in Euc.* 41.5), διοπτρική (Procl. *in Euc.* 42.4) and ὀπτική (Procl. *in Euc.* 38.12, 40.9, 59.23, 63.8). Second, Hero uses the term αὐτοματοποιητική at I.1 [2.7]; but cf. also I.1 [2.3]. The parallel forms cited by Schmidt are not parallel *stricto sensu*. They are suffixed either with -ικός or with -ποιϊκός, not with -ποιητικός.⁹⁹ Furthermore, in none of the passages quoted do they serve as titles. The fact that Hero (twice) uses the term αὐτοματοποιητική does not necessarily imply that the treatise originally bore the title *Περὶ αὐτοματοποιητικῆς*.¹⁰⁰

Schmidt's discussion is hardly satisfactory, not only for the reasons just given but also for three other main reasons: (1) he overlooked earlier emendations; (2) he misinterpreted an important piece of literary evidence which so far has not been placed in its proper perspective (see below); (3) he left out of

⁹⁶ Manuscripts **Ea** and **Pc** have, respectively, Τοῦ αὐτοῦ and Ἡρώωνος τοῦ αὐτοῦ. These readings can be explained by the fact that in both manuscripts the text of the *Automata* is immediately preceded by Hero's *Pneumatica*.

⁹⁷ See especially the discussions in Horsfall (1981) and Fredouille (1997).

⁹⁸ Tittel (1912: 1049), *contra*, argues that both titles deviate from standard titlature of mathematical and technical works, which usually requires the nominative plural neuter. Murphy 8 n. 1 follows suit, stating that 'neither title is consistent with the forms of other titles of technical works, such as Heron's *Belopoiika*'. This needs correction. The oldest attested title is partly consistent with other Heronian titles (see below). On the characteristic openness of *Περὶ*-writings, see Dubischar (2015: 565).

⁹⁹ Similarly, Schmidt, *Supplementum* 53 compares *Περὶ αὐτοματοποιητικῶν* with *nominative* plural neuter forms ending either in -ικά (*Πνευματικά*) or in -ποιϊκά (*Βελοποιϊκά*, *Λιμενοποιϊκά*, *Ὀργανοποιϊκά*). He quotes *Λιμενοποιϊκά* and *Ὀργανοποιϊκά*, respectively, from Ph. *Bel.* 49.2 and 49.3. Philo, however, uses the term ὀργανοποιϊκά not as a title but only as an alternative designation for artillery-construction: νῦν δὲ καθήκει λέγειν, καθότι ἐξ ἀρχῆς διάταξιν ἐποίησάμεθα πρὸς σέ, περὶ τῶν βελοποιϊκῶν, ὑπὸ δὲ τινῶν ὀργανοποιϊκῶν καλουμένων, Ph. *Bel.* 49.2-4.

¹⁰⁰ The term αὐτοματοποιητική is unattested outside the *Automata*.

account the presence of a separate heading introducing the second part of the treatise (*Περὶ στατῶν αὐτομάτων*).¹⁰¹ Discussion of such heading will be relegated to the end of the section because it can be used as corroborating evidence for what I think is the original main title.

4.1 Earlier emendations

The following emendations of *Περὶ αὐτοματοποιητικῶν* have been proposed: *Περὶ αὐτοματοποιήτων* (Dindorf *ap. TGL* s.v. αὐτοματοποιητικός), *Περὶ αὐτοματοποιϊκῶν* (Wescher 1867: 71 unnumbered n.), and *Αὐτοματοποιϊκά* (Prou 117 with n. 1; Tittel 1912: 1049).¹⁰² These conjectures are improbable, not least because neither αὐτοματοποίητος nor αὐτοματοποιϊκός is attested in extant Greek literature.¹⁰³ Dindorf's αὐτοματοποιήτων is curious for two reasons. First, Dindorf suggests emending αὐτοματοποιητικῆς (I.1 [2.3]) to αὐτοματοποιϊκῆς, and therefore we would rather expect αὐτοματοποιϊκῶν. Second, αὐτοματοποίητος is a deliberate calque on the Latin *automatopoētus*: *automatopoetasque* [Turnebus : -*pictasque* vel -*pitasque* codd.] *machinas* (Vitr. 9.8.4). Unlike its Latin counterpart, the Greek term looks like a passive verbal adjective, and so would not yield a reasonable sense ('*On things made automatically*'). The nominative plural neuter *Αὐτοματοποιϊκά* is preferable to *Περὶ αὐτοματοποιϊκῶν* (cf. above, n. 98), but neither Wescher's comparison between similar forms (βελοποιϊκά, ὀργανοποιϊκά, λιμενοποιϊκά)¹⁰⁴ nor Prou's reference to Plato's use of ὀψοποιϊκός (*Smp.* 187e4, *Grg.* 463b3, 464d4, 465b1, 465d6; cf.

¹⁰¹ This heading is omitted in **Ab**, **Ad**, **Bb**, **Ha**, **M**, **Mb** and **Pd**. Prou 132 erroneously maintains that only four of the Paris manuscripts (**Pb**, **Pe**, **Pf**, **Pg**) divide the treatise into two books. The remaining three Paris manuscripts each have a different heading: *Περὶ στατῶν αὐτομάτων* (**Pa**), *Περὶ τῶν στατῶν αὐτομάτων* (**Pc**) and *Περὶ τῶν στατῶν βιβλίον* [*sic*] β (**Ph**). The *editio princeps* has no heading, whereas Prou and Schmidt have, respectively, *Περὶ τῶν στατῶν αὐτομάτων* (despite Murphy 8 n. 1) and *Περὶ στατῶν αὐτομάτων*.

¹⁰² Tybjerg (2005: 206) and Wikander (2008: 788) curiously adopt transliterations of *Αὐτοματοποιϊκά*.

¹⁰³ The oxytone form αὐτοματοποιητός, cited by *TLL* s.v. *automatopoeetus* and *OLD* s.v. *automatopoētus*, is likewise unattested, and its accented last syllable violates the rules for the accentuation of verbal adjectives in -τος (on which, see KB 1.538-9).

¹⁰⁴ Wescher (1867: 71 unnumbered n.) refers to the term αὐτοματοποιία, along with βελοποιία, ὀργανοποιία, λιμενοποιία, μηχανοποιία and ἐργοποιία. I was, however, unable to find an attestation of the term.

also 465d2 and 500e5)¹⁰⁵ provides sufficient grounds for preferring a compound in -ποιϊκός. For the same reason, αὐτοματοποιητικῆς (I.1 [2.3]) should not be emended to αὐτοματοποιϊκῆς.

4.2 The original main title

None of the emendations proposed so far answers our question, and we are still left with the two alternative forms of the title. The title *Περὶ αὐτοματοποιητικῆς* is clearly preferable to *Περὶ αὐτοματοποιητικῶν*, and it is reasonable to think that the latter form arose as a corruption of the former. However, as will become clear below, other Heronian titles which follow the same pattern consist of *περί* followed by the name of an object rather than that of a *technē*.

The answer to our question comes from the following passage in book 8 of the *Mathematical Collection* of Pappus (fourth century CE):

καλοῦσι δὲ μηχανικοὺς οἱ παλαιοὶ καὶ τοὺς θαυμασιουργούς, ὧν οἱ μὲν διὰ πνευμάτων φιλοτεχνοῦσιν, ὥς Ἑρῶν πνευματικοῖς, οἱ δὲ διὰ νευρίων καὶ σπάρτων ἐμπύχων κινήσεις δοκοῦσι μιμεῖσθαι, ὥς Ἑρῶν αὐτομάτοις καὶ ζυγίοις, ἄλλοι δὲ διὰ τῶν ἐφ' ὕδατος ὀχουμένων, ὥς Ἀρχιμήδης ὀχουμένοις, ἢ τῶν δι' ὕδατος ὥρολογίων, ὥς Ἑρῶν ὑδρίοις, ἃ δὲ καὶ τῇ γνωμονικῇ θεωρίᾳ κοινωνοῦντα φαίνεται.¹⁰⁶

5 ὑδρίοις scripsi secutus Martin (infra, n. 108); vide etiam locos ibi citatos : ὑδρεῖοις codd., rec. Commandino et Hultsch

The ancients also call mechanics the wonder-workers, of whom some pursue their art by means of air, as Hero in *Pneumatica*, some seem to imitate the movements of animate things by means of little strings and cords, as Hero in *Automata* and *Balances*, others by means of bodies floating in water, as Archimedes in *Floating Bodies*, or by means of water-driven clocks, as Hero in *Hydria*, which in fact appears cognate with the study of sun-dials.

¹⁰⁵ On ὀψοποιϊκός as preferable to ὀψοποιητικός, see *TGL* s.v. ὀψοποιητικός. Other examples of the alternation between -ποιϊκός and -ποιητικός are ἀνδριαντοποιϊκή/ἀνδριαντοποιητική, ἀρτοποιοποιϊκός/ἀρτοποιητικός, πιλοποιϊκός/πιλοποιητικός, σιτοποιϊκός/σιτοποιητικός.

¹⁰⁶ Papp. 1024.24-1026.2.

Scholars almost unanimously agree that the term αὐτόματος is here used as the title of the treatise.¹⁰⁷ This interpretation is supported by the mention not only of other works of Hero¹⁰⁸ but also of Archimedes' *Floating Bodies*.¹⁰⁹ If one were to follow Tittel (1912: 1049) in interpreting these words as referring to classes of objects, one would have to understand the dative as instrumental, which does not accord well with the repeated use of διά + genitive. Moreover, a reference to Archimedean floating bodies would be redundant, because the corresponding generic class is designated as τὰ ἐφ' ὕδατος ὀχούμενα. The crucial issue here is not, I believe, whether the plural datives refer to ancient works, but rather what sources lie behind the passage. Berryman's (2009: 59-60) comparison between the classifications of mechanics by Pappus (*Syn.* 1024.12-1026.4) and Proclus (*in Euc.* 41.3-18, drawing on the first-century BCE writer Geminus)¹¹⁰ led her to conclude that Pappus, too, drew on a doxographical tradition.¹¹¹ This is correct as far as it goes, but it does not go far enough. The question of sources proves much more complex. Hultsch (1877: 115, 119-22) identifies two main sources for Pappus' book 8. He feels that one major source was Hero's *Mechanica*, which he believes to have been excerpted by Pappus himself in the introduction.¹¹² However, he contends that an informed but less polished interpolator, in addition to excerpting Hero's *Mechanica*, supplemented the introduction, and particularly

¹⁰⁷ Schmidt, *Supplementum* 54 n. 1 takes the words αὐτομάτοις καὶ ζυγίοις as an inaccurate quotation of the title. But see below, n. 108.

¹⁰⁸ Hero's now lost *Zύγια* (or *Περὶ ζυγίων*?), which was presumably concerned with entertainment devices such as statuettes balanced on pins (Martin 1854: 42 with n. 3), is mentioned nowhere else. By contrast, Hero's treatise on water-clocks (*Υδρία* or, following Martin 1854: 42, *Περὶ ὑδρίων*) is also known as *Περὶ ὑδρίων ὀροσκοπείων* (Procl. *Hyp.* 4.73; cf. Papp. *in Ptol.* 89.5). Martin (1854: 42 with n. 5) cites a third form of the title (*Περὶ ὑδροσκοπείων*), which replaces *Περὶ ὑδρίων ὀροσκοπείων* not in Halma's (1820: 107) edition of Proclus' *Hypotyposis* but in the edition of the same work by Grynaeus (1540: 42). The title of the work cited by Pappus may be an abbreviated form of *Περὶ ὑδρίων ὀροσκοπείων*.

¹⁰⁹ Archimedes' treatise is so titled (*Ἀρχιμήδους Ὀχουμένων*) in the so-called Archimedes Palimpsest (on which, see Netz *et al.* 2011); cf. also Hero, *Spir.* 24.11-12 (ἀπεδείχθη γὰρ Ἀρχιμήδει ἐν τοῖς Ὀχουμένοις, etc.). Str. 1.3.11 refers to it as *Περὶ τῶν ὀχουμένων*.

¹¹⁰ Berryman (2009: 60 n. 21), for instance, draws attention to the parallel between Pappus' words οἱ δὲ διὰ... μιμῆσθαι and Procl. *in Euc.* 41.8-9 τὰ δὲ διὰ νεύρων καὶ σπάρτων ἐμψύχους ὀλκὰς καὶ κινήσεις ἀπομιμουμένων; cf. also οἱ μὲν διὰ... φιλοτεχνούσιν with τὰ μὲν διὰ πνῶν φιλοτεχνούσα (Procl. *in Euc.* 41.8-9).

¹¹¹ Hultsch (1877: 119) had already recognised that the two classifications were drawn from a similar or identical source.

¹¹² Hultsch (1877: 123 n. 12) considers Pappus' definition of mechanics (*Syn.* 1022.8-13) to have been repeated *verbatim* from Hero's *Mechanica*. See Cuomo (2000: 105) for the tentative suggestion that this definition derives from some work by Ptolemy.

the section devoted to the classification of the discipline,¹¹³ on the basis of a commentarial tradition originating from the so-called Heronian school (οἱ περὶ τὸν Ἡρώνα μηχανικοί, Papp. 1022.14-15).¹¹⁴ The main implication which concerns us here is that, even if Hero did not mention his work on automata in his *Mechanica*, the interpolator's source contained a reference to the title of the treatise. This title, which likely reflects an earlier stage of the tradition, can be reconstructed as *Περὶ αὐτομάτων* on analogy with other Heronian titles, such as *Περὶ δίοπτρας*, *Περὶ ὑδρίων ὁροσκοπείων* and possibly also **Περὶ ζυγίων*.¹¹⁵

How are we to explain, then, the oldest attested title? The most plausible explanation involves the assumption that the treatise came to lack all or part of its title. The fact that in the manuscripts the title is not repeated at the end may be taken as a tentative indication that it was originally placed at the beginning, rather than at the end, of the roll.¹¹⁶ If so, it would have been more easily exposed to damage, and hence more likely to be replaced by a different title.¹¹⁷ The presence of an internal title, of course, does not preclude that the roll also bore an external title, but ancient testimony suggests that such titles (usually written on fragile parchment labels) were optionally added at the request of the owner of the roll.¹¹⁸ The title *Περὶ αὐτοματοποιητικῆς*, therefore, may have been supplied on the basis of the opening of the treatise, all the more likely because ancient works were often identified by their incipits.¹¹⁹ So, while we cannot be

¹¹³ That the references to ancient works in Pappus' passage have been added by a later interpolator is suggested by the use of the simple dative. In other, similar cases, Pappus employs ἐν + dative: *Syn.* 54.31-56.1, 270.20-1, 270.31-272.1, 272.2, 298.3, 312.7, 312.20-1, 360.19-20, 410.22-3, 1026.9, 1060.5-6, 1064.8, 1068.3, 1068.19-21, 1106.13-14, 1114.5-6, 1130.7.

¹¹⁴ *Contra*, Cuomo (2000: 105) and Vitrac (2009: 167 and 174 n. 41), who assume direct dependence of Pappus upon Hero.

¹¹⁵ See above, n. 108. Another mechanical treatise has a comparable title, Athenaeus *Mechanicus* *Περὶ μηχανημάτων*.

¹¹⁶ Turner (1987: 13): '[t]he habit of putting a title at the end is carried over into the codex form'; see also Holtz (1997: 479). For a recent discussion of initial and end-titles in papyri, see Caroli (2007: 52-60).

¹¹⁷ The inclusion of Hero's name could be taken as an argument against my proposal. However, we can envisage at least three scenarios: (1) only the title of the work was lost, either entirely or in part; (2) the whole title was lost, but the scribe supplying the information was already acquainted with the work; (3) the whole title or part of it was lost after the treatise had been transcribed into codex form, but the authorship was deduced from the fact that the manuscript contained other Heronian works.

¹¹⁸ See Cic. *Att.* 4.4a, 4.5 and 4.8, with Oliver (1951: 243) and Holtz (1997: 472 n. with 12). For a comprehensive discussion of external titles, see Caroli (2007: 23-52).

¹¹⁹ See Nachmanson (1941: 37, 49-50); Kenney (1970); Holtz (1997: 470, 474-77).

entirely sure that *Περὶ αὐτομάτων* is Hero's original title, it has two clear advantages. First, albeit based on thin evidence, it rests on more solid and authoritative ground than *Περὶ αὐτοματοποιητικῆς*, which is attested only relatively late. Second, it conforms more closely to the author's mode of titling. If Hero had used *αὐτοματοποιητικός* in the main title, he would probably have chosen a plural neuter (*Αὐτοματοποιητικά*).¹²⁰

4.3 *Περὶ στατῶν αὐτομάτων*

There are three possible interpretations of *Περὶ στατῶν αὐτομάτων*. (1) it is a genuine title; (2) it is an interpolation;¹²¹ (3) it is a subtitle.¹²² The first two interpretations support the idea that neither of the manuscript titles is the original one, although (1) is more unlikely than (2). Let us briefly consider these three options:

(1) This interpretation does not tally well with the main titles, which do not include indication of the book number. If either of them were the original title, one would have expected Hero to use the same title for both books and to specify the book number, just as he does with his *Pneumatica*. Furthermore, accepting this interpretation would seemingly require that the original title be *Περὶ ὑπαγόντων αὐτομάτων*, which is not only unsupported but also unsuited to the more general character of the first book (cf. I-II);

(2) This interpretation begs the question of how the heading was supplied. It might have been based on XX.1 [64.7] *περὶ δὲ τῶν στατῶν αὐτομάτων* (cf. also I.8 [49–50]), but the absence of the article would seem to suggest that the scribe had *Περὶ αὐτομάτων* before his eyes. This interpretation, therefore, may serve as indirect confirmation of our reconstructed title;

(3) This interpretation, at least as I understand it, presupposes that the heading is genuine. Two possibilities arise here: either Hero felt the need to add

¹²⁰ See above, nn. 98-9.

¹²¹ Prou 132 (albeit without substantiation). It is unclear to me why he prefers the (corrupted) form *Περὶ τῶν στατῶν αὐτομάτων* (above, n. 101).

¹²² Murphy 8 n. 1. See also Schmidt 404, who prints this heading in a smaller type than that employed for the main title.

a subtitle to the second part of the work, or (more likely) he found it in book 6 of Philo's *Mechanical Collection*.¹²³

While I cannot exclude entirely (2), I am inclined to interpret this heading as a genuine, originally Philonian subtitle.

5. THE WORK

Hero's *Περὶ αὐτομάτων* is our only extant treatise entirely devoted to the design and construction of ancient automata. It belongs to what might be called the 'supergenre' of technical ekphrasis, namely the verbal description of a technical artefact.¹²⁴ 'Supergenre' is a more appropriate term than 'genre' not only because distinctions between different genres of technical literature are not easy to grasp, but also because such descriptions appear across a variety of text types and genres, ranging *inter alia* from epigram and didactic poetry to commentary, instruction manual and epistolary prose.¹²⁵ The treatise situates itself firmly in the context of Graeco-Roman culture, while also being highly reminiscent of Hellenistic mechanical works. It combines an interest in a single specialised subject, such as is found in Philo's *Belopoeica* (and such as would presumably have been found in his lost treatise on automata),¹²⁶ with a systematic, unified approach typical of other works of its time (the most important example certainly being Vitruvius' *De Architectura*); Hero achieves this mainly in two

¹²³ The title of Philo's now-lost book 6 has been reconstructed by Orinsky-Neugebauer-Drachmann (1941: 53) as *Αὐτοματοποιητικά* (cf. also 'Automatopoeetica', Haase 1847a: 432). Some modern scholars prefer *Αὐτοματοποιικά* (in its transliterated form), although without providing any explanation (Lewis 1997: 86; Tybjerg 2008: 654; Beacham 2013: 21; Koetsier-Kerle 2016: 354; Rance 2016: 444; Whitehead 2016: 21).

¹²⁴ For groundbreaking work in this area, see Roby (2016).

¹²⁵ For discussion of the different genres included under the umbrella of technical ekphrasis, see Roby (2016: 26-42). On 'supergenre', see Hutchinson (2013).

¹²⁶ The content of book 6 of Philo's *Mechanical Collection* was first inferred from Hero's comments about Philo being his source (XX.1 [64.8-10]; Haase 1847a: 432), and it has been commonly accepted that it represents the work mentioned by Philo himself in ch. 3 of his *Pneumatica*, called *De arbitriis mirabilibus* (*On Marvellous Opinions*) in the Latin version (*Spir.* 462.26-7). Carra de Vaux (1902: 37) disputed the content of the book and suggested emending the corresponding Arabic text to read *On Marvellous Instruments* (*Des instruments merveilleux*). A comparison with the classification of sciences in Avicenna's *Treatise on Wisdom* (*resā 'il fi 'l-hikmet*) led him to argue that the book dealt with water-organs. This argument has not gained favour among classicists, and although Carra de Vaux may be right to think that 'opinions' does not make much sense, I cannot see why the reconstructed title cannot refer to automata.

ways: by intertwining several disciplines, both scientific and non-scientific, and, as we shall see, through presenting variations upon a range of mechanical arrangements.¹²⁷

As has been already noted, Hero presents us with two types of automaton, one mobile (ὑπαγόν) and the other stationary (στατόν). Both these, as Hero himself describes them (in BOOK ONE and BOOK TWO, respectively),¹²⁸ are devices that use stored energy to perform a series of actions. One shared characteristic of both the mobile and the stationary automaton is their power source. Both devices are powered by a falling counterweight, although Hero (II.6 [10.8-9]) mentions another possible power source for mobile automata – the so-called ὕσπληγξ, a mechanism analogous to the torsion engine for catapults and which is not used anywhere in the treatise. (In BOOK TWO, we find a different device, mostly referred to as ὕσπλήγγιον, which is used to produce a vertically swinging motion; see further below, §5.2 and Comm. on II.6 [10.4-8].) It is interesting to note that, when Hero uses the term αὐτόματος (or its corresponding adverb αὐτομάτως) elsewhere, he refers to motion that is brought about by means of a falling weight.¹²⁹ But, mechanics (and indeed language) aside, Hero does not tell us exactly where or how his automata were used, nor does he tell who his treatise (or similar treatises) was intended for. He is, on the other hand, *slightly* more explicit about his sources, for, apart from Philo, he acknowledges the existence of a tradition that he has inherited and improved upon.

In what follows, I shall first provide a convenient overview of the structure of the text, paying particular attention to the editorial practices of previous editors. This will be followed by a brief critical description of the contents of the treatise and then by a discussion of its historical, literary and cultural background. This, in turn, will allow me to consider possible settings in which Hero's automata might have been used. After that, I shall discuss the

¹²⁷ See Roby (2016: 266-8 and, more generally, 86-9).

¹²⁸ The division into books goes back to Hero himself (I.8 [6.3] and [6.7]). It is partly retained in one of the manuscripts, **Ph**, where the second book is numbered in the margin (above, n. 101).

¹²⁹ I owe this point to Prof. Isabel Ruffell. For αὐτόματος, cf. *Spir.* 70.10 and 198.17; for αὐτομάτως, cf. *Dioptr.* 202.28, *Spir.* 90.13 (quoted below), 174.2, 180.12, 182.1-2. On Hero's concept of αὐτόματος, cf. Comm. on I.2 [2.10-11].

intended audience of the treatise. Finally, after discussing Hero's use of sources, I shall address the status of the text.

5.1 Internal arrangement

The treatise, as it stands in the Teubner edition, is divided into 30 chapters, further subdivided into 161 numbered sections. Chapter divisions mostly follow manuscript practice,¹³⁰ with a few being supplied by Schmidt (XXIII, XXIV, XXVI, XXX).¹³¹ Further subsectioning, as well as chapter and section numbering, is a modern innovation, although two points should be noted: (1) XI.9 and XIII.3 are marked off, respectively, in **G** (with an L-shaped sign) and **T** (by rubric); (2) Schmidt's claim (app. crit. to 342.11) that in the manuscripts the chapters are not numbered is misleading because, even though no corresponding numbers are found, in **M** chh. V-XXVII are (discontinuously) numbered 1-16.¹³² The division into chapters is also adopted in Thévenot (31 indented paragraphs) and, as far as BOOK TWO alone is concerned, Prou (11 θεωρήματα, subdivided into 45 sections), but in neither case does it reflect faithfully obvious divisions in the manuscripts.

Hero's material is usually organised into (semi-)coherent, largely self-contained units, with cross-references both within and between books. However, order is far from being the governing principle of the text. Although Hero uses signposting throughout (most of) the work,¹³³ the narrative is interspersed with digressions, and some topics are addressed in more than one place.

For readers wishing to obtain an overall impression of the contents of the treatise, Schmidt's edition provides a useful starting point. His translation is accompanied by 44 descriptive headings, which are placed both at the beginning of each chapter and at the beginning of (or within) sections. Most of these are

¹³⁰ The only exceptions are chh. X and XXI, which are made to begin, respectively, with IX.6 [32.17] ὥς δὲ δεῖ and XX.5 [68.3] περὶ τῆς τῶν.

¹³¹ Schmidt is silent about the first three editorial interventions. Ch. XXIX was first marked off by Haase (noted by Schmidt in his app. crit. ad loc.).

¹³² This series omits number 15, while also including number 7 twice (i.e. chh. XII and XIII, although in the latter case the number seems to have been added by a later hand). The marginal number 13 is placed next to XXIV.2 [80.14] rather than at the beginning of the chapter. The following chapters are not numbered: VIII, XV, XX, XXI, XXII, XXIII, XXIV, XXVI.

¹³³ In this regard, see Baldi 46^r [erroneously numbered 45] n. 5, cited by Prou 135 with n. 49.

incorporated, sometimes in a slightly altered form, in his list of contents (Schmidt 510-11), which, however, does not give a complete idea of the internal arrangement of the work. Prou, too, provides descriptors, though not always satisfactory. Here I attempt to remedy these shortcomings by offering a fairly detailed outline of the structure of the text:

BOOK ONE

I [2.3-6.8] Preface

I.1 [2.3-8] Automata-making

I.2-7 [2.9- 4.22] Mobile and stationary automata

I.7 [4.22-6.2] Automata-makers as wonder-workers

I.8 [6.3-8] Affirming one's authority

II [6.9-14.16] Constructional preamble

II.1 [6.9-17] Ideal ground surface, trackway

II.2 [6.17-8.2] Lightweight materials

II.3 [8.3-8] Smoothness of components, different types of bearings (κνώ-
δακες and χοινικίδες)

II.4 [8.9-12] Importance of lubrication

II.4-5 [8.12-10.3] Cords

II.6 [10.4-10] Two different power systems (ὑσπληγξ and counterweight)

II.7 [10.11-19] Basic components (axle, wheels and case)

II.8 [12.1-3] Calibrating the forces

II.8 [12.3-6] Movements other than locomotion

II.8-9 [12.6-13] Descent of the counterweight in the tube, trickling grains

II.9 [12.13-15] Principle of movement explained

II.10 [12.16-19] Unequal movements

II.10-11 [12.19-14.10] More on cords

II.12 [14.11-16] Novelty and pleasantness of the arrangement

III-IV [14.17-20.7] Arrangement and performance of the mobile automaton

III.1 [14.17-16.4] Dimensions of the mobile automaton (base, column
shafts, architrave)

III.2-4 [16.5-22] Arrangement of the mobile automaton

IV.1-4 [18.1-20.1] Performance of the mobile automaton

IV.4 [20.1-6] General advice on dimensions

V-VI [20.8-26.5] Forms of motion. Straight-line motion

V.1-2 [20.8-17] Forms of motion (straight-line, circular and rectangular)

V.3-5 [20.18-22.20] Straight-line forward motion, drive mechanism

VI.1-2 [22.21-24.15] Straight-line backward motion

- VI.3 [24.16-20] Repeated forward and backward motion
- V.4 [26.1-5] Side elevation of the case
- VII-VIII [26.6-30.2] Circular motion
 - VII [26.6-28.3] Configuration for circular motion
 - VIII [28.4-30.2] Mathematical principles underlying circular motion
- IX-X [30.3-34.24] Rectangular motion
 - IX.1-3 [30.3-24] Configuration for rectangular motion
 - IX.4.-6 [32.1-17] Pauses, initiation of movement (digression)
 - IX.6-X [32.17-34.24] Raising and lowering the wheels (re-configuration)
- XI [36.1-42.8] Other forms of motion
 - XI.1 [36.1-5] Polygonal and snake-like motion
 - XI.2-5 [36.6-38.6] First configuration for snake-like motion
 - XI.6 [38.7-14] Measurement of cords (digression)
 - XI.7 [38.15-40.2] Second configuration for snake-like motion
 - XI.8 [40.3-7] Technical superiority of pivots (κνώδακες) over hubs (χοινι-κίδες)
 - XI.9-10 [40.8-42.3] Third configuration for snake-like motion
 - XI.11 [42.4-8] Smooth and easy movement of the case
- XII [42.9-44.14] Other movements. Lighting of the altar(s)
- XIII.1-7 [44.15-48.13] Pouring of liquids
- XIII.7-9 [48.13-50.15] Rotation of Dionysus and Nike
- XIV [50.16-52.6] Sound of kettledrums and cymbals
- XV [52.7-54.7] Descending garlands
- XVI [54.8-56.10] Dancing Bacchantes
- XVII.1-2 [56.11-58.2] Concealing the cords
- XVII.3-XVIII [58.3-60.9] Increasing the range (I). Potentially unsuccessful modifications
 - XVII.3 [58.3-8] Bigger wheels, smaller axle
 - XVIII.1-3 [58.9-60.3] Mechanical transmission
 - XVIII.3-4 [60.3-9] Increasing the range of other movements, repeated rotation of Dionysus
- XIX [60.10-62.20] Increasing the range (II). Two-counterweight system

Book Two

- XX [64.2-68.4] Preface
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 - XXX.1-5 [106.4-108.14] Bolt of lightning
 - XXX.5-6 [108.14-110.10] Disappearance of Ajax
- XXX.7 [110.11-15] Epilogue

5.2 Contents

As is clear enough from the schematic outline I have just provided, BOOK ONE (which takes up two-thirds of the treatise) opens with a preface which introduces the whole work. There Hero describes the types of automata that can be built, articulates his position as author and editor, and, more importantly, makes a number of claims to justify his enterprise. He gives two main reasons for dealing

with the topic of automata-making, both grounded in the tradition that he has received. First, there is a striking element of wonder involved in the viewing and contemplating of automata (τὸ ἔκπληκτον τῆς θεωρίας, I.1 [2.5]).¹³⁴ He is explicit that the construction of automata belongs to a broader tradition of spectacular marvels (θαυματουργία or θαυματοποιία; I.7 [4.22-6.2]), and we have seen in §4.2 above that in later times Hero's treatise was still felt to belong to such tradition (the later interpolator in Pappus). Second, the making of automata incorporates all types of mechanical knowledge (I.1 [2.6-8]), and thus requires a complex variety of craftsmanship (τὸ ποικίλον τῆς... δημιουργίας, I.1 [2.4-5]). This claim certainly serves to magnify Hero's own work, but it is not without grounds: when we read Hero's descriptions of the automata (particularly of the mobile type), we find that he makes use of hydraulic elements, with comparisons drawn between some of his devices and artillery technology (II.6 [10.6-8], XIII.9 [50.10-11]).¹³⁵

The rest of the book deals almost in its entirety with the mobile automaton (which I will describe shortly). Hero's account is preceded by an explanation of the (pre)conditions leading to mechanical success (or failure), including information on procedures and principles for achieving motion (I have called this section 'Constructional preamble'). Two points of particular interest emerge from this portion of the treatise. One is Hero's concern with the characteristics of the surface on which mobile automata (such as wheeled shrines or temples) move (II.1-2 [6.9-17]). The ground should be as flat and as even as possible to ensure smooth operation of the device. As an alternative, Hero suggests the use of a prepared trackway consisting of grooved wooden boards so that the wheels of the automaton may be made to fit into the grooves. This arrangement recalls the railways used in theatrical performances to move either entire stage buildings (theatres at Sparta and Megalopolis) or ἐκκυκλήματα (theatre at Eretria).¹³⁶ What is particularly suggestive here is the fact that, as noted by Lewis (2001a: 9), in the Hellenistic theatre at Megalopolis the rails

¹³⁴ In a recent article, Tybjerg (2003) has argued that Hero deploys wonder to strengthen the epistemological claims of mechanics, but this misses the point of the text. For discussion, see Comm. ad loc.

¹³⁵ Keenan-Jones-Ruffell-McGookin (2016: 168). See also Roby (2016: 267).

¹³⁶ See Lewis (2010a: 9-10), with references. On the ἐκκύκλημα, cf. Poll. 4.128; Taplin (1977: 442-3); Newiger (1990: 34-9); Csapo-Slater (1994: 270-3); and, most recently, Brioso Sánchez (2006).

were probably made of wood rather than stone (as in the other examples) because no trace of them has been found. The second point is that all the movements in both the mobile and the stationary automaton are ultimately brought about by the vertical action of a single counterweight (although in fact Hero later suggests the addition of a second counterweight in the mobile automaton; see below, §5.6.2). The counterweight is located in a (rectangular) tube (σούριγξ) full of millet or mustard seeds (dry sand is instead preferred in the stationary automaton to extend the length of the performance: cf. Comm. on II.9 [12.10-13]). When these grains trickle through an aperture situated at the bottom of the tube (which is opened manually: IX.5 [32.12-13]), the counterweight falls down, drawing cords which are connected to various instruments – mainly axles, but also drums, pulleys and other cylindrical components. To regulate the timing of movements, there are slack hanks of cord glued onto the appropriate place with wax (II.10 [12.19-14.6]). These are Hero's tools. He makes no use of toothed wheels or gears, and yet he achieves a variety of results.¹³⁷

Hero's mobile automaton is essentially a roofed shrine of Dionysus set on top of four columns (**Fig. 1**), with Bacchantes dancing around the figure of the god, self-kindling altars (one in front and the other behind him), a miniature panther effigy lying at his feet and a winged Nike holding a wreath and resting upon the apex. The automaton is about 1.5 metres high – Hero gives only approximate dimensions of some of the automaton's components such as the base, the column shafts and the (Ionic) architrave (III.1 [14.17-16.4]) – and moves upon wheels which are housed in a small casing (πλινθίον). In its basic form, it moves forward in a straight line, stops, performs a ritual scene ('apotheosis of Dionysus'),¹³⁸ and then moves back to its starting point. Other patterns of movements are possible, either theoretically (rectangular) or

¹³⁷ Drachmann (1963a: 197). The absence of gearing can probably be explained on technical grounds, such as problems related to wear and excessive heaviness (Murphy 40 n. 6). The first attested example of gearing is found in Ctesibius' water-clock (rack and pinion), on which see below, §5.3. Later examples include the famous Antikythera mechanism (second century BCE), a device used to calculate astronomical positions, Vitruvius' mention of wheels engaging each other at right angles in water-mills (*De Arch.* 10.5.2) and Hero's use of different types of gearing in the *dioptra* (cf. esp. *Dioptr.* ch. 3), in the odometer (*Dioptr.* ch. 34), and in the *baroulcos*, which latter would allow (albeit probably only theoretically) a weight of 1000 talents to be lifted with a power of five talents (above, n. 8). For discussion and further references, see Drachmann (1963a: 200-3).

¹³⁸ I borrow the descriptive phrase of Prou 138 ('*Apothéose de Bacchus*').

practically (circular, snake-like, and perhaps also the more elusive polygonal), and the automaton can also move back and forth many times;¹³⁹ Hero likewise suggests several possibilities for extending the range of motion, although only the last one might have proved feasible at all (further details on all these configurations are given below and/or in the Commentary ad locc.). When the automaton comes to a halt, the upper display animates itself. The altar in front of Dionysus flares up. Milk or water spurts from the thyrsus the god holds in his left hand, and wine flows out of his cup onto the panther lying beneath.¹⁴⁰ Garlands sink down from the upper part of the peristyle, immediately followed by the Bacchantes dancing in a circle to the accompaniment of kettledrums and cymbals. When the sound ceases, the figures of Dionysus and Nike rotate simultaneously 180 degrees. All these movements (except for the sinking of the garlands) repeat themselves once more, with Dionysus and Nike returning to their original position.

BOOK Two opens with a preface that provides a transition between the two main themes of the treatise. The stationary automaton consists of a box called *πίναξ*, which is set on top of a wooden pillar. Hero does not provide any information about its size,¹⁴¹ although we are informed that in neither type of automaton should the dimensions raise suspicion of human agency (IV.4 [20.1-6]). The *πίναξ* type mimics the function of a theatre, with, among other things, doors that open and close and figures painted on a series of backdrops which possess movable parts. (On the theatrical relevance of the term *πίναξ*, see below, §5.4.2.) In this case, too, there is scope for repeating the movements (XXI.1 [68.8-14]; cf. I.3-4 [2.17-4.9]). The particular specimen chosen by Hero seems to go back to Philo, although it is not impossible that it predates him by

¹³⁹ Some movements are presented as occurring ‘(as many times) as we may choose’ (X.3 [30.23], XI.11 [42.7]). Similar expressions are very frequent in the treatise and seem to emphasise the mechanical (or scenic) adaptability of the devices.

¹⁴⁰ Much the same arrangement can be seen in two Pompeian frescoes, known respectively as ‘Bacchus and Silenus’ (Temple of Apollo, VII, vii, A; MANN, inv. no. 9269) and ‘Bacchus and Vesuvius’ (House of the Centennial, IX, viii, 6; MANN, inv. no. 112286). This iconography probably serves to characterise Dionysus as an almighty god who can unlock the secrets of the universe. I shall explore this in a forthcoming article, provisionally entitled ‘Unlocking the Secrets of the Universe: Hero, *Aut.* 3-4 and *AP* 14.24”.

¹⁴¹ See, however, XXIII.1 [74.7-9], where he advises that the boards forming the frame (*πλινθίων*) of the *πίναξ* should be one-sixth as wide as their length. Marshall (2003: 261) suggests that perhaps the box is ‘over a metre wide’.

some years.¹⁴² Before describing his preferred model, which presents the myth of Nauplius through a succession of five scenes,¹⁴³ Hero (XXII.1 [70.4-14]) recalls the earliest type of stationary automaton. This presumably pre-Philonian model featured a succession of three scenes, allowing only limited movements (opening and closing of doors, a painted face with moving eyes, and dropping backdrops).¹⁴⁴ On the other hand, in Philo's model, which was improved upon by Hero (see further below, §5.6), we find a wider range of movements (cf. the remark at XXII.2 [70.14-16], which suggests that the passage was already to be found in Philo). The animated scenes of the automaton can be briefly summarised as follows:

(1) Twelve figures are painted on the backdrop of the box. They represent the Greeks (Δαναοί or Ἀχαιοί) repairing their ships after the capture of Troy.¹⁴⁵ Their right arms, which are made of horn, are attached flush to the backdrop and move up and down. Their movement is brought about by means of a star-shaped wheel (ἀστερίσκος) which repeatedly hits a counterweighted bar (ὕσπλήγγιον) behind the backdrop;

(2) The ships are launched. They are painted on a piece of cloth the same size as the backdrop of the box and which is held up by means of a cord fixed to a pin. When the cord is released, the cloth drops under the weight of a rod which is attached to its underside (the same principle is at work at XV.4 [54.6-7] and XXX.3 [108.1-2]). Similar dropping backgrounds are used in scenes (4) and (5);

¹⁴² This view has been forcefully held by Marshall (2003: 263), although he did not elaborate further. But see below, n. 144.

¹⁴³ On the main sources for this myth, and on the connections between the automaton's narrative and Sophocles' fragmentary *Nauplius Pyrkaeus*, see Marshall (2003). Although I cannot here examine the relationship of the automaton to tragic drama, I must nevertheless mention the position taken by Weil (1882: 417-8). He contended that only the fourth scene may have been inspired by Sophocles' play, while also attributing the first and the second to Hero. I find his position pessimistic and his attribution unconvincing because it ignores the Philonian origin of the material. The question certainly deserves to be studied in greater detail, particularly in light of the existence of Roman tragic evidence (Pac. *Trag. inc.* 45 Ribbeck = Cic. *Div.* 1.14.24).

¹⁴⁴ Marshall (2003: 275 n. 40) has suggested that the Nauplius automaton represents an expansion of a three-scene pre-Philonian model on the basis that the third scene follows closely on the second in the same way the fifth follows closely on the fourth. For a brief description of the individual scenes, see below.

¹⁴⁵ Brumbaugh (1966: 124) misreads Δαναῶν (XXII.3 [70.22]) as Δαναΐδων ('Danaïds'), and hence takes these figures to represent 'nymphs' (pp. 54, 114, 124; cf. 'busy shipbuilding girls', p. 126). The manuscripts have no such variant reading here.

(3) The ships sail by, with dolphins swimming alongside. The sailing of the ships is achieved by means of a horizontally scrolling backdrop made of papyrus and with sky and sea painted on it. The scroll slides back and forth rapidly so as to produce the illusion that the ships painted on the cloth background actually move. The dolphins are each fixed by means of an axle to a pulley hidden inside the floor of the stage. As the pulley rotates, the dolphins appear to swim, plunging down into the hidden cavity which shields the door axle;

(4) Nauplius and Athena appear, both painted on a backdrop. Nauplius holds up a blazing torch. The lighting of the torch is effected by means of a lamp hidden inside the top part of the box. The lamp is set inside a chest which has a triangular bronze plate. When the plate slides, turning around its own pin, the flame reaches up and sets the shavings on fire. A similar arrangement is used to kindle the altars of Dionysus;

(5) The ships are wrecked, Athena appears on stage and (Locrian) Ajax drowns being struck by lightning. The last dropping backdrop depicts the shipwreck and Ajax swimming. The rotating figure of Athena is placed on a pivoted base, which allows it to flip up and down, with two cords pulling it from below. (This mechanism, as we shall see below, replaces Philo's earlier use of a μηχανή.) The base is either on or connected to an axle. The combination of these two elements forms a mechanical joint (ἰσχύριον).¹⁴⁶ As for the painted figure of Ajax, it is made to disappear by being covered by a piece of cloth of its size. The cloth is painted so as to resemble the rest of the background, and drops down at exactly the same time as the board depicting the bolt of lightning.

The description of the stationary automaton is followed by two cursory, interrelated observations (XXX.7 [110.11-14]): (a) that all the movements occur in the same way (with explicit reference to the forward motion of the mobile automaton, πορεία); (b) that all the πίνακες are managed by the very means that have been put into practice in Hero's chosen arrangement. These reassert the mechanical and scenic flexibility of contemporary automata as opposed to their distant predecessors, thus picking up a number of remarks made throughout the treatise (I.8 [6.4-7], II.12 [14.12-14], XXI.2 [70.2-3]). The text, as it stands now,

¹⁴⁶ I follow here the reconstruction by Ruffell (forthcoming 1) rather than that by Querfurth (in Schmidt LXIII-VIII), which is overdetailed and not entirely reliable.

ends in a lacuna, which probably contained a statement as to the variability of the stories represented in the stationary automata (XXX.7 [110.14-15]): πλὴν ὅτι διαλλάσσονται <***>.¹⁴⁷

5.3 Historical, literary and cultural background

In order to contextualise Hero's models, it is necessary to examine briefly the literary and cultural history of ancient automata. Three main strands can be identified, all of which are somehow connected to the dimension of wonder and amazement. The first strand concerns epic representations of automata. These imaginary automata differ from actual models especially as far as their power source is concerned. The second strand concerns isolated inventions, dating to the Classical period, that use different power sources but which have limited programmability compared to later examples. The third strand concerns the development of a systematised tradition, which begins in the Hellenistic period and extends well into the Imperial era (and beyond).¹⁴⁸ This tradition is associated, in particular, with the name of Ctesibius.

The idea of creating self-working artefacts can be traced back as far as Homer. In the *Iliad*, we find the first examples of mythical automata, such as the

¹⁴⁷ Most manuscripts have the marginal note λείπει at the end of the text. This note has received different interpretations. Prou 248 n. f seems to have taken it as referring to a lacuna occurring before διαλλάσσονται, which he filled with the word μύθοις. In his edition, Schmidt (app. crit. to 452.12) apparently took it as referring to the incomplete state of the text ('[u]nvollständig', Schmidt 452 n. 3), but dismissed it as false (see already Baldi 47^v n. 22). Olivieri (1901: 431) wrongly regarded it as indicating a big lacuna in BOOK ONE (see further below, §5.6.2). In his rebuttal of this view, Schmidt (1903: 277 with n. 1) presented two alternatives: (1) it refers to a lacuna at the very end of the treatise; (2) it refers to a lacuna which contained the complement of διαλλάσσονται (in his edition he printed a lacuna before the verb and suggested adding τοῖς μύθοις). I am decidedly inclined to take it as referring to the treatise's lacunose ending rather than to the (apparently) incomplete state of the text (on which, see below, n. 255). It is hard to decide whether to place the lacuna before or after διαλλάσσονται (XXX.7 [110.14-15]) because the weight of textual evidence does not favour either position (complement before: *Spir.* 10.16-17; complement after: *Mech. Frag.* 2.1 = Papp. 1116.12). Unlike Schmidt, I have opted for the latter option. If διαλλάσσονται occupied the very end of the folio (possibly a verso), the concluding word(s) of the treatise could have easily been lost. The words added in the margin of **Ab** by a second hand clearly make no sense: κατὰ τοὺς ἀνομοίους καὶ πολλοὺς τῶν διαγεγραμμένων τρόπους ('according to the many dissimilar ways of the things described [?]').

¹⁴⁸ I will not consider late antiquity both because the evidence for this period is particularly difficult and because it is not directly relevant to establishing a context for Hero's automata.

self-opening gates of Olympus (*Il.* 5.749 = 8.393) and Hephaestus' self-moving tripods (*Il.* 18.369-79), the latter being described as 'a wonder to behold' (θαῦμα ἰδέσθαι, line 377). The workshop of Hephaestus also famously includes golden maidservants 'with a mind, voice and strength of their own' (τῆς ἐν μὲν νόος ἐστὶ μετὰ φρεσίν, ἐν δὲ καὶ αὐδὴ | καὶ σθένος, *Il.* 18.419-20) and bellows which respond to their master's will (*Il.* 18.468-73). It is unclear, indeed unlikely, that any of these devices involves mechanical skill, and other examples such as the Phaeacians' self-piloting ships (*Od.* 8.555-62) or the Hesiodic Pandora (*Op.* 60-82) certainly support the idea that divine power is the source of animation.¹⁴⁹

The first securely attested examples of mechanically automated devices date to the fourth century BCE. One such example is found in Aulus Gellius (second century CE), who, drawing on Favorinus, ascribes to the philosopher and statesman Archytas of Tarentum the construction of a wooden flying dove (Gell. 10.12.8-10 = Archyt. T A10a Huffman). Although the account lacks necessary details concerning the design of the device, Gellius, who concludes his passage with a direct quotation from his source, informs us that it operated through a combination of air and counterweight (*libramentis suspensum et aura spiritus inclusa atque occulta concitum*). Schmidt (1904: 349-351) offered a reconstruction of the functioning of the device, arguing that the dove was propelled by compressed air which was released by a valve (nowhere mentioned by Gellius). His reconstruction is not unproblematic, not least because such a use of compressed air is unparalleled in later pneumatic devices, and it is more likely that air was introduced through a tube to provide the initial impulse.¹⁵⁰ Nevertheless, he also suggests, rather convincingly, that the dove was used as part of larger display to impress guests at a symposium.¹⁵¹ This certainly accords

¹⁴⁹ Berryman (2009: 24-8), who singles out the moving statues of Daedalus (Pl. *Men.* 97d4-e5; cf. *Euthphr.* 11b9-d1) as the best candidates for mechanical automata. In my view, she pushes her argument to an extreme. The fact that mechanics did not develop until the fourth century BCE does not mean that later authors could not look upon mythical automata as precursors of existing models, as exemplified, for instance, by Arist. *Pol.* 1235b34-1254a1. For other mythical automata, see, among others, Cambiano (1994: 624).

¹⁵⁰ For full discussion, see Huffman (2005: 572-7), who observes that the dove is unlikely to have been free-flying.

¹⁵¹ This suggestion has been accepted by Schürmann (1991: 175). See also Schürmann (2002: 36).

well with the characterisation of the dove as something wonderful (*admirabile*).¹⁵²

Archytas' flying dove is in some respects a unicum in the history of ancient automata. This is so not only and not so much because of its pneumatic power source (we have seen that Hero envisages two different power sources of automata, neither of which involves a fluid) but rather because, as noted by Huffman (2005: 575), there are no other examples of birds actually flying. Nonetheless, it is tempting to associate its origin with the technological advances that took place under Dionysius I, tyrant of Syracuse (405–367 BCE), with whom Archytas was allied and under whose patronage could have been involved in the development of catapults.¹⁵³ A similar association is made by a third-century CE source. In a fictive letter from the philosopher Speusippus to the tyrant Dion ([Socr.] *Ep.* 35 Hercher),¹⁵⁴ the Syracusans are congratulated for rejecting a number of innovations of Dionysius I, including the habit of sending ingenious (σοφά) devices to Delphi in the form of dedications. Although the text is rather cryptic, there is mention made of Apollo (perhaps a playful allusion to Dionysius I)¹⁵⁵ 'hearing and seeing the small cart running around in the hippodrome automatically' (ἀκούσας καὶ τὸ ἀμάξιον ἰδὼν τὸ ἐν τῷ ἵπποδρόμῳ περιτρέχον αὐτόματον). Here there is no indication as to what might have powered the automaton. Rehm (1937: 329) ruled out the use of a counterweight (it is not clear where it would go) and suggested, on the basis of his reconstruction of Demetrius' snail (see below), that the cart was operated by two men, one turning a windlass to drive the wheels and the other changing the direction of motion.

¹⁵² Berryman (2009: 96) speculates that Archytas' device was in fact either a catapult (?) or, more probably, a catapult projectile because, whereas Gellius refers to it as *simulacrum columbae* ('representation of a dove'), his source simply calls it περιστέρα ('dove'), possibly appealing to the rather widespread use of animal names in describing machines and their parts (on which, see esp. von Staden 1998, as well as the use in the *Automata* of the terms κοχλίας and κόραξ, indicating respectively a 'screw' and a 'hook': chh. X and XV, respectively). This is extremely unlikely for at least two reasons. First, mechanical writers never use the verbs *volare* or *πέτομαι* (which are found in Gellius' account) to refer to the hurling of a projectile. Second, although the precise mechanism of the device remains conjectural, there is no parallel for the combination of air and counterweight in artillery technology. For Ctesibius' air-powered catapult, see below, §5.6.

¹⁵³ See Berryman (2009: 95), citing Keyser (1994: 31). The connection between automata, artillery and Dionysius I is investigated by Ruffell (forthcoming 2), on whose work I base the discussion which follows.

¹⁵⁴ On the date of the *Socratic Epistles*, see Sykutris (1933: 106-22).

¹⁵⁵ Rehm (1937: 330), endorsed by Ruffell (forthcoming 2).

Technical considerations aside, the cart is explicitly described as small (although it is difficult to say how small) and would probably not have contained all that equipment. A perhaps more likely power source would be something like Hero's ὕσπληγξ, involving sinew spring, which would have been well known to the technical entourage of Dionysius I.

The tradition exemplified by the pseudo-Socratic letter is also reflected in the works of Aristotle, where we find the first references to αὐτόματα (whether or not in direct connection with wonder). The two sources I have in mind are Arist. *GA* 734b7-15 and *MA* 701b2-10, where automata are invoked as analogues for living organisms or biological processes (in the former case for sperm motility, in the latter for animal locomotion). In both cases the point of comparison is the ability to turn an initial impetus into a causative sequence of actions.¹⁵⁶ The second passage distinguishes two types of device, αὐτόματα and ἀμάξια, but the text is particularly difficult and corrupt,¹⁵⁷ and it is not clear exactly how these devices would have functioned. Nussbaum's (1976: 149-50) interpretation is that the first type refers to marionettes which move thanks to a system of interlinking pegs and cables (στρέβλαι), but this is perhaps overprecise and it is not impossible that their power source may have been the unwinding of cords (possibly of sinew) from a windlass.¹⁵⁸ As for the cart mentioned in line 5, I am not entirely convinced that it was fully automatic (as Ruffell has it),¹⁵⁹ but

¹⁵⁶ Berryman (2009: 72-3); cf. also Cambiano (1994: 628-9). Particularly relevant in this connection are [Arist.] *Mu.* 398b13-16 and Gal. *Foet. Form.* 4.688-9 Kühn.

¹⁵⁷ For discussion of the text-critical problems, see Nussbaum (1976: 146-52). For consideration of the passage in connection with Micheli's (2005) argument that Aristotle's automata were powered by a ὕσπληγξ, see Comm. on II.6 [10.4-8].

¹⁵⁸ A suggestion made by Ruffell (forthcoming 2) and already found *in nuce* in Nussbaum (1976: 150). The 'interlinking pegs' in Nussbaum's reconstruction depend on an emendation of the quite problematic phrase κρουόντων ἀλλήλας τὰς στρέβλας (line 3) to κρουόντων ἄλληλα τῶν ξύλων. In commenting on this passage, Philoponus (*in GA* 77.16-17) talks of pieces of wood transmitting motion to one another 'through some mechanism' (διὰ τινος μηχανῆς), which, as noted by Ruffell (forthcoming 1), admits of several different reconstructions.

¹⁵⁹ Again, the text is rather problematic. Most manuscripts describe the cart as ὅπερ ὁχούμενον αὐτὸ κινεῖ εἰς εὐθύ (others have either ὥσπερ ὁχούμενος or ὥσπερ ὁχούμενον in place of ὅπερ ὁχούμενον). The most commonly accepted emendation is ὁ γὰρ ὁχούμενος, which makes αὐτὸ the object of κινεῖ. Ruffell (forthcoming 2) suggests an ingenious emendation of αὐτὸ to αὐτὸν on the basis of the reflexive use of κινέω in Aristotle's discussion of how something can be αὐτοκίνητος (*Ph.* 258a-15), which makes the cart automatic. This slight emendation is very tempting, especially in view of the evidence from the pseudo-Socratic epistle discussed above. But it seems to me that Aristotle implies a contrast between the initial impetus of motion (κινεῖ) and the subsequent steering of the device (κινεῖται). See further below.

certainly Aristotle refers to an automatic change in the pattern of movement (κύκλῳ κινεῖται τῷ ἀνίσους ἔχειν τοὺς τροχούς... καθάπερ ἐν τοῖς κυλίνδροις, lines 5-6). Both the mention of unequal wheels and the (rather obscure) comparison in relation to solid geometry bring the device closer to Hero's mobile automaton.¹⁶⁰

It is only in the Hellenistic period that we see a sustained tradition of automata-making emerge. Perhaps the originator and first exponent of such tradition was Ctesibius of Alexandria (c.300–230 BCE),¹⁶¹ who, according to Vitruvius (*De Arch.* 9.8.2; cf. 9.8.4), was also the founder of pneumatics as a discipline. Unfortunately, none of his works has survived, but we know that he wrote two works, called respectively *Pneumatic Theorems* (Πνευματικὰ θεωρήματα, Ph. Bel. 77.12) and *Commentaries* (Ῥπομνήματα, Ath. Mech. 29.10).¹⁶² Although best known for inventing the fire-pump, the water-clock and, as we have seen, the water-organ, he also described the application of hydraulic principles to the construction of automata of the kind we find in Philo's and Hero's *Pneumatica* (singing birds and drinking animals).¹⁶³ Vitruvius selected only Ctesibius' more practical inventions and instead left out of consideration 'those things which are not for the sake of necessity, but for the sake of pleasure' (*quae non sunt ad necessitatem sed ad deliciarum voluntatem*), referring the reader for more details to Ctesibius' own *Commentaries* (*De Arch.* 10.7.5).

¹⁶⁰ See Ruffell (forthcoming 2). For the tentative suggestion that κύλινδρος here refers to a children's toy, see Nussbaum (1978: 348).

¹⁶¹ On the question of Ctesibius' date, see Drachmann (1948: 1-3). Ctesibius may not have been originally from Alexandria, for Ath. Mech. 29.9 calls him ὁ Ἀσκληνός (Fraser 1972: 2.622-3 n. 445). But the ethnic is conjectural (cf. Wescher 1867: 29) and unattested outside this passage and Hero Byz. 263.1, as noted by Whitehead-Blyth (2004: 142). The ethnic of Boeotian Ascrea is Ἀσκραῖος, and Vit. 9.8.2 refers to Ctesibius as *Alexandrinus*. Whitehead-Blyth (2004: 142) speculate that the obscure ethnic provides an indication that Ctesibius' family migrated to Alexandria from rural Boeotia, unless another otherwise unknown Ascrea (or Ascre) is meant.

¹⁶² Fraser (1972: 1.431) erroneously cites the latter as Ῥπομνηματισμοί. But cf. Fraser (1972: 2.619 n. 421).

¹⁶³ Vit. 9.8.4 and 10.7.4, with Oleson (1984: 125) and Callebat (2003: 168-170). For singing birds and drinking animals, see below. Granger (1934: 313 nn. 1-2) unintelligibly connects the term *angubatae* in Vit. 10.7.4 with the automatic owl appearing in *Spir.* ch. 1.16 (erroneously cited as I.91), on which see below. The meaning of this *hapax* is uncertain, but it seems to refer to the kind of figure described in Ph. *Spir.* ch. 36 (Drachmann 1948: 70; cf. Callebat 2003: 169), today commonly called 'Cartesian diver'. Hero's owl, at any rate, is made to turn rather than walk, as presupposed by Granger's (1934: 313) translation of the term ('walking automata').

That Ctesibius was associated with the royal court at Alexandria under the reign of Ptolemy II Philadelphus (283–246 BCE) is made clear from Hedylus’ description (in Athenaeus) of Ctesibius’ invention of a drinking-horn (ῥυτόν),¹⁶⁴ to which I shall return in more detail below. Similar drinking vessels are later encountered in Philo’s and Hero’s *Pneumatica*, and some of them would have provided spectacular entertainment at royal symposia.¹⁶⁵ Ctesibius’ horn, however, belongs to a different class of devices, namely that of ‘temple automata’: automata that were placed in temples, sanctuaries and similar confined religious settings, either temporarily or permanently, and which mainly served either (politico-)religious or decorative functions (or both).¹⁶⁶ At the same time, it also belongs to what Bur (2016: 79 n. 31) calls ‘dedicated inventions’, that is to say dedications which were used to promote scientific and technological achievements.¹⁶⁷ Although much of our evidence for automatic contrivances comes from the Roman Imperial era (Hero’s *Automata* and *Pneumatica*) or is filtered through the Arabic tradition (Philo’s *Pneumatica*), automata must have featured prominently among such Hellenistic achievements because they were an offshoot of the intellectual activity of the Mouseion, whose scientific work reached its apex in the third century BCE.¹⁶⁸

Ctesibius’ horn was shaped in the form of the head of the Egyptian god Bes and featured an automatically operated trumpet which would emit a shrill sound (λιγὸν ἦχον, *HE* 1845) when the wine flowed out. It was dedicated by Ctesibius himself in the temple of Arsinoe Zephyritis (erected 270 BCE), and was probably placed upon a pedestal or plinth on which was inscribed Hedylus’

¹⁶⁴ Ath. 11.497d-e = Hedyl. *HE* 1843-1852. The text is particularly corrupt. For full discussion, see Galli Calderini (1984: 87-91), with ample bibliography.

¹⁶⁵ See Schürmann (1991: 164-70); Wikander (2008: 790); and, most recently, Bur (2016: 7, 130). For (sympotic) drinking-horns, cf. Ph. *Spir.* ch. 16; Hero, *Spir.* chh. 1.18, 2.13, 2.28. Bur (2016: 130) rightly notes, albeit without citing any source, that Hero’s use of the term κρατήρ provides an indication of the sympotic context of such devices. The term occurs 30 times in Hero’s *Pneumatica* (*Spir.* chh. 1.14, 1.19-20, 2.12, 2.31, 2.34-5).

¹⁶⁶ For ‘temple automata’, see Schürmann (1991: 224-34). See also, most recently, Bur (2016: 127-87), who, however, includes in this category not only devices specifically flagged for use in temples – such as, for instance, Hero’s holy water dispenser (*Spir.* ch. 1.21) or the so-called ἀγνιστήριον (‘ritual purifier’, *Spir.* ch. 2.32) – but also devices which are reasonably thought to have been used in private houses. See below.

¹⁶⁷ Fraser (1972: 1.412-3) mentions two other examples: Eratosthenes’ dedicatory epigram on the duplication of the cube (Eutoc. in Arch. *Sph. Cyl.* III 96.10-27 Heiberg-Stamatis = Powell, *Coll. Alex.* fr. 35) and Archimedes’ inscribed tombstone (Cic. *Tusc.* 5.64-6).

¹⁶⁸ See Fraser (1972: 1.319, 426) and Fragaki (2012: 30), with further bibliography.

dedicatory epigram.¹⁶⁹ The poem leaves no doubt that its true focus is on the figure of Ctesibius,¹⁷⁰ who is emphatically praised for his clever invention (ἀλλὰ Κτησιβίου σοφὸν εὔρημα τίετε τοῦτο, *HE* 1851). This can be understood as part of a larger propagandistic strategy in the Ptolemaic programme of political legitimization and self-aggrandisement,¹⁷¹ as the following example will make clear.

At a slightly earlier date than the erection of Arsinoe's temple, Alexandria was host to a procession which took place at the Ptolemaia festival in the city's stadium, the so-called Grand Procession. The procession, which occurred under Ptolemy's auspices (probably in the years 280–275 BCE), was described by Callixeinus of Rhodes in a work called *On Alexandria* (Ath. 197c-203b ≡ Callix. *FGrH* 627 F 2; Rice 1983) and consisted of a series of smaller processions. The surviving text deals almost entirely with the procession of Dionysus, featuring a conspicuous display of wealth. The procession was opened by Silens, Satyrs, Nikai with golden wings and other lavishly ornamented figures, followed by the statues of Dionysus (4.60 metres high) and Nysa (3.70 metres high), both seated on a cart (Ath. 197e-198f). Holding a thyrsus in its left hand, the statue of Nysa – a personification of Dionysus' birthplace, following (Rice 1983: 66-8), rather than the god's nurse – stood up 'mechanically without anyone laying their hands on it' (μηχανικῶς οὐδενὸς τὰς χεῖρας προσάγοντος)¹⁷² and then sat back down after pouring a libation of milk (Ath. 198f). Callixeinus' description, textually and iconographically, recalls Hero's mobile automaton, all the more so as the seated statue of Dionysus appears to pour a libation.¹⁷³ The functioning of Nysa is unclear. Rice (1983: 63-65), picking up and amplifying an earlier suggestion by Fraser (1972: 1.426), suggested that Nysa was the work of Ctesibius (or of someone directly influenced by him) on two grounds: (a) that Ctesibius was connected with the royal court (as noted above); and (b) that the Nysa statue (which was presumably built with hinged joints) was powered by a

¹⁶⁹ Fraser (1972: 1.413). Rice (1982: 63) is more cautious about identifying the dedicator with Ctesibius, although she does not explain.

¹⁷⁰ Fraser (1972: 1.413), endorsed by Rice (1982: 63).

¹⁷¹ On the propagandistic intent of the poem, see Galli Calderini (1984: 89).

¹⁷² Compare the expression Hero uses at I.6 [4.18] μηδενὸς προσιόντος.

¹⁷³ Rice (1983: 59) notes that, because the liquid is not specified, the statue was probably only positioned to suggest the action. *Contra* (rightly, in my opinion), Ruffell (forthcoming 2), who observes that the procession involves a large amount of fluids.

cam-and-lever arrangement,¹⁷⁴ a solution which would accord well with Ctesibius' experiments with the transference of circular motion into linear motion attested by the rack-and-pinion mechanism of his water-clock (Vitr. 9.8.4-7). Leaving aside the attribution (and therefore also leaving aside Ctesibius' water-clock), it is worth noting that, while the cam seems to be attested already in the third century BCE,¹⁷⁵ Rice's reconstruction is perhaps overdetailed, and Nysa's repeated action could just as easily have been achieved using cords and axles in the fashion usually favoured by Hero and apparently also Philo.¹⁷⁶ Be that as it may, what needs to be stressed here is that the prominence assigned to Nysa by being positioned at the beginning of the procession anticipates and confirms the propagandistic intent of the parade, which is most fully accomplished through the celebration of the Indian campaign of Dionysus-Alexander (Ath. 200d-201c),¹⁷⁷ and thereby of Ptolemy's own legacy. What we have here, it seems to me, is a combination of propaganda, entertainment and the element of wonder.

A similar example of this, but with more emphasis on technical mastery, is described in Polybius' *Histories*. Polybius, quoting the Athenian orator Demochares, briefly mentions a mobile type of automaton associated with one of Demochares' sworn enemies, Demetrius of Phalerum, the governor of Athens in the years 317–307 BCE (Plb. 12.13.11 = Democh. *FGrH* 75 F 4). The automaton was part of a procession through the theatre of Dionysus, which probably took place at the Dionysia festival of 309/308 BCE (Rehm 1937: 317): 'a snail moving automatically went before him [sc. Demetrius] in the procession, spitting up slime' (κοχλίας αὐτομάτως βαδίζων προηγέιτο τῆς πομπῆς αὐτοῦ, σίαλον ἀναπτύων). On the basis of a highly speculative reconstruction by Schramm (in Rehm-Schramm 1929: 20-1 with Figs. 6-7) of a siege-engine known as the ἐλέπολις ('city-taker') of Posidonius of Macedonia and described by Bito (*Constr.* 53.4-56.7),¹⁷⁸ Rehm (1937) reconstructed Demetrius' snail as a

¹⁷⁴ For similar reconstructions, see Lewis (1997: 84-5) and, most recently, Koetsier-Kerle (2016: 354-5).

¹⁷⁵ Lewis (1997: 94) on Plin. *Nat.* 18.97, cited by Wilson (2002: 16).

¹⁷⁶ Ruffell (forthcoming 1), citing as a paradigmatic example ch. XXIII of the present treatise.

¹⁷⁷ See Rice (1983: 67), citing Fraser (1972: 1.202).

¹⁷⁸ For criticism of Schramm's reconstruction, see Marsden (1971: 89) and, more fully, Lendle (1983: 49-53) and Campbell (2003: 12-13).

three-wheeled, human-operated automaton, three or four metres in height, with its two rear wheels powered by an internal treadmill and a controllable wheel at the front. The implausibility of Rehm's reconstruction aside,¹⁷⁹ comparison with the ὀμάξια discussed above, on which Demetrius' snail seems to have been an advance,¹⁸⁰ and with Hero's mobile automaton suggests to me that this model should have been considerably smaller than the size suggested by Rehm. What brings the snail closer after all to its Heronian successor is the combination of motion (in this case, probably linear) with the projection of liquids. It is certainly noteworthy that, in describing Dionysus' libation, Hero uses the terms ἀναπτυσμός (IV.3 [18.17]) and ἀναπτύζω (XIII.1 [44.15-16]), themselves ultimately derived from ἀναπτύω,¹⁸¹ which suggests that the same or a similar hydraulic mechanism was at work in Demetrius' snail. At any rate, although frustratingly silent about the mechanics of the device, Demochares' testimony is particularly valuable for what it tells us about the snail's performance context.

The theatrical use of automata is better attested in the Roman Imperial period, although most of our evidence from that time more directly relates to private settings (see below). Two examples seem to me particularly relevant. The first example concerns Nero's famous attempt to kill his mother Agrippina in 59 CE. One of our sources for the episode (or, in fact, series of episodes) is Suetonius,¹⁸² who tells us that Nero, after trying to kill her with poison and then contriving a collapsing ceiling (*lacunaria, quae noctu super dormientem laxata machina deciderent*), devised a 'collapsible boat' (*solutilis navis*) to destroy her either by shipwreck or by the falling down of its cabin (*vel naufragio vel camarae ruina*).¹⁸³ The (ultimately unsuccessful) idea of such boat is attributed by Tacitus (*Ann.* 14.3) to Nero's former preceptor Anicetus, who would be responsible for Agrippina's death (*Tac. Ann.* 14.8; *D.C. Epit.* 61.13.4-5),

¹⁷⁹ For a full discussion, I refer the reader to Ruffell (forthcoming 2). I am not particularly interested here in the strictly technical side of things. Bito's passage dealing with the internal mechanisms of the ἐλέπολις is also textually problematic (cf. esp. Bito 55.4-5).

¹⁸⁰ So Ruffell (forthcoming 2).

¹⁸¹ Note, however, that the quotation of Demochares' text known to us through the indirect tradition contains the variant reading ἀποπτύων ('spitting out'; Suda σ 352).

¹⁸² Suet. *Nero* 34.2-4. Other sources: Tac. *Ann.* 14.1-13 and *D.C. Epit.* 61.12-13. Although the three accounts differ significantly in detail, they are likely to have been derived at least in part from a common source (see Devillers 1995).

¹⁸³ Suet. *Nero* 34.2. Tac. *Ann.* 14.5 has a collapsing, lead-weighted ceiling, which does not seem to be automatic; see Ruffell (forthcoming 2).

whereas in Cassius Dio it is associated with the emperor's future wife, Poppaea Sabina, who herself instigated the murder, and with whom Nero watched an automatic collapsing ship in the theatre (D.C. *Epit.* 61.12.2-3):

ναῦν ἰδόντες ἐν τῷ θεάτρῳ διαλυομένην τε αὐτὴν ἐφ' ἑαυτῆς καὶ τινα θηρία ἀφιείσαν, καὶ συνισταμένην αὖ πάλιν ὥστε καὶ ἐρρῶσθαι, τοιαύτην ἑτέραν ταχέως ἐναυπηγήσαντο.

Having seen in the theatre a ship parting asunder by itself, letting loose some beasts and coming back together so as to be robust again, they quickly had one such ship built for themselves.¹⁸⁴

The second example is found in Apuleius' *Metamorphoses*, where the protagonist Lucius attends the pantomime performance of the *Judgment of Paris* in the Roman colony of Corinth (*Met.* 10.30-4). The scene is Mount Ida, a towering wooden structure 'built with sublime craftsmanship' (*sublimi[s] instructus fabrica*), with abundant vegetation, goats grazing among the low grasses and a fountain pouring out water from the mountain's peak (*Met.* 10.30). The performance prominently features dances of Juno, Minerva and Venus (all with attendants) with the aulos accompaniment, followed by a moralising interlude on the corruptness of judges. It concludes with a wine-saffron mixture showering down from the peak of the mountain and a spectacular earthquake (*Met.* 34):

tunc de summo montis cacumine per quandam latentem fistulam in excelsum prorumpit vino crocus diluta sparsimque defluens pascentis circa capellas odoro perpluit imbre, donec in meliorem maculatae speciem canitiem propriam luteo colore mutarent. Iamque tota suave fraglante cavea montem illum ligneum terrae vorago decepit.

¹⁸⁴ Exactly how the ship would have disassembled itself remains unclear, but Tacitus' account is slightly more accurate (*Ann.* 14.3): *ergo navem posse componi docet* [sc. *Anicetus*] *cuius pars ipso in mari per artem soluta effunderet ignaram* [sc. *Agrippinam*].

Then, from the very peak of the mountain, through a concealed pipe, saffron dissolved in wine spurted out high into the air and, flowing down in scattered streams, sprinkled the goats grazing all around with a fragrant shower, until, dyed to a greater beauty, they changed their natural hoariness to a golden-yellow colour. And now that the whole theatre was smelling sweetly, a chasm in the earth swallowed the wooden mountain.

Although Dio's account may have been rooted in anecdote,¹⁸⁵ and despite the fictional nature of Apuleius' story, both examples reflect theatrical practices which were common in early Imperial times. The best evidence comes from Seneca's *Epistles*. In one such letter, Seneca contrasts the true *sapiens* with someone who invents (among other ingenious devices) 'a system for squeezing saffron up to an immense height from concealed pipes' (*quemadmodum in immensam altitudinem crocum latentibus fistulis exprimat*, *Ep.* 90.15), whereas in another letter he describes 'unexpected devices such as objects fitting together which come apart, or separate objects which join together automatically, or objects which stand erect, then gradually collapse' (*ex inopinato varietates aut dehiscentibus quae cohaerebant, aut his, quae distabant, sua sponte coeuntibus aut his, quae eminebant, paulatim in se residentibus*, *Ep.* 88.22).¹⁸⁶ Significantly, these contrivances are mentioned as a product of the arts of entertainment (*artes ludicrae*), which, as Seneca says, 'aim at the pleasure of the eyes and the ears' (*ad voluptatem oculorum atque aurium tendunt*; cf. *Vitr.* 10.7.5 *quae delectationibus oculorum et aurium usu sensus eblandiantur*, in reference to Ctesibius' devices).

Quite the same taste for entertainment is known to have been catered for at the private banquets of the Roman elite. Our richest source of information is Petronius. In the *Cena*, we find frequent references to automata (or closely

¹⁸⁵ It is difficult to say whether Dio's account is more historically reliable than Tacitus'. What seems certain, however, is that Tacitus' amplification of Anicetus' role was due not only to his being the prefect of the fleet at Misenum but also, and more especially, to the similarities with the Tacitean account of the death of Octavia (*Ann.* 14.60-4), in which Anicetus also played a significant role (*Ann.* 14.62); see Devillers (1995: 327-8, 330-1), with bibliography. On Tacitus' account of Octavia's death, see, more recently, Murgatroyd (2008).

¹⁸⁶ The comparison between the Apuleius passage and the Senecan *Epistles* has been noted by Zimmerman (2000: 367, 403, 405); see also Denard (2007: 154). For the widespread use of saffron in theatres, Zimmerman (2000: 403) also refers to *Lucr.* 2.416, *Hor. Ep.* 2.1.79-80 (*crocus* used metonymically for 'stage') and *Ov. Ars* 1.103.

related devices), and the use of actual theatrical apparatus contributes to transforming Trimalchio's house into a stage (see Panayotakis 1995: 91). So, at the beginning of the dinner, Trimalchio is introduced to us as having a 'clock and a uniformed trumpeter in his dining-room' (*horologium in triclinio et bucinatorem... subornatum*, *Sat.* 26.9), where *horologium* seems to refer to a water-clock.¹⁸⁷ Later on we encounter the narrator Encolpius watching out for a not better-specified *automatum* (*Sat.* 54.4) and then, a few chapters later, a self-opening ceiling which lets out a hoop adorned with golden crowns and perfumes (*Sat.* 60.1-3; note especially the description of the automaton as an earthquake: *lacunaria sonare coeperunt totumque triclinium intremuit*, *Sat.* 60.1).¹⁸⁸ Immediately following this is a dish with a pastry figure of Priapus holding fruits and grapes which spurt out saffron when touched (*Sat.* 60.4-6). Yet another textual portion presents us with the famous zodiac dish (*Sat.* 35.1-6 and 36.1-4). The disclosure of the upper part of the dish allows the guests to see an impressive display (*Sat.* 36.1): birds, sow's udders, a winged hare made to look like Pegasus, and fish swimming in a spiced sauce which was flowing out of the wine-skins of the four figures of the satyr Marsyas at the corners of the dish (*notavimus etiam circa angulos repositorii Marsyas quattuor, ex quorum utriculis garum piperatum currebat super pisces, qui quasi in euripo natabant*). This was certainly intended to resemble public fountains, which were often ornamented with statues (see, for instance, *Prop.* 2.32.15-16), and Hero in the *Pneumatica* describes similar figures of Satyrs pouring water from their skins (*Spir.* chh. 1.37 and 2.15).¹⁸⁹ Meerwaldt (1921: 411 with n. 1) argued that the swimming of the

¹⁸⁷ See Raïos (2000: 26), citing Maiuri (1945: 151) and Smith (1975: 53). Baldwin (1978: 87 n. 3), on the other hand, is undecided between a sundial and a clepsydra. Meerwaldt (1921: 407-10), apparently endorsed by Raïos (2000: 26-7), proposed to interpret the participle *subornatus* as *instructus* ('equipped') and the phrase *horologium... et bucinatorem... subornatum* as *horologium bucinatore subornatum*, which makes Trimalchio's trumpeter an automatic piece of apparatus (*contra*, Panayotakis 1995: 57 n. 13). The text makes sense as it stands, and Meerwaldt's interpretation strains the syntax. Raïos (2000: 26) wrongly attributes to Meerwaldt the claim that, in its remaining occurrences in the *Satyricon* (21.2, 36.2, 40.5), *subornatus* means either 'dressed in' or 'decorated with'. Cf. Meerwaldt (1921: 408): '[u]t his locis [sc. citatis], ita I. I. mea quidem sententia **proprio**, non translato, **sensu** est accipiendum *subornare*' (my emphasis).

¹⁸⁸ Similar movable ceilings were rather common in upper-class Roman dining-rooms; see *Sen. Ep.* 90.15; *Suet. Nero* 31.2; *Val. Max.* 9.1.5; *Macr. S.* 3.13.8; Panayotakis (1995: 90); Raïos (2000: 21-2, 24).

¹⁸⁹ Meerwaldt (1921: 411), cited by Raïos (2000: 28).

fish was effected automatically by mechanical means, an argument which seems to have ultimately depended on the difficulties he faced in interpreting the text (he printed the reading *quicunque* instead of *qui quasî*). On the basis of a (highly dubious) comparison with Hero's configuration for circular motion in the mobile automaton and with the mechanisms used in *Spir.* ch. 1.16, he suggested that there was a hollow cavity beneath the 'canal' (*euripo*), with a cord wound around an axle and having one end passing through two pulleys and the other end attached to a counterweight; the falling weight would have caused the axle to turn by pulling upon the cord, which would, in turn, rotate the canal.¹⁹⁰ There are many problems with this reconstruction. I shall mention only the most conspicuous. First, there is no hint in the text that the basin containing the fish would rotate; the fish are merely said to 'swim', and the illusion could easily be achieved by the constant flowing of *garum*. Second, the circular pattern of motion in the mobile automaton in reality depends on the fact that the two main driving wheels are not of the same size, but the outer wheel is bigger than the inner one (cf. synopsis on VII-VIII). Third, the mechanical arrangement found in *Spir.* ch. 1.16 features a combination of weights and pneumatic elements and, although a counterweight is used to turn an axle (only 180 degrees), the ultimate power source of the whole device is running water. Here mechanical means are used to animate a scene where birds stop singing when an owl turns to look at them and then resume when it looks away again (*Spir.* 90.10-16):

κατασκευάζεται οὖν ἥτοι ἐν κρήνῃ ἢ ἐν ἄντρῳ ἢ καθόλου ὅπου ἐπίρρυτον ὕδωρ ἐστίν, ὄρνεα πλείονα διακείμενα καὶ τούτοις παρακειμένη γλαύξ, ἥτις ἐπιστρέφεται αὐτομάτως παρὰ τὰ ὄρνεα καὶ πάλιν ἀποστρέφεται· καὶ ἀποστραφείσης μὲν φθέγγονται τὰ ὄρνεα, ἐπιστραφείσης δὲ πρὸς αὐτὰ οὐκέτι φθέγγονται. καὶ τοῦτο πλεονάκις γίνεται.

Several birds are constructed, arranged either in a spring or in a cave or generally wherever there is running water, and beside them an owl which turns automatically towards the birds and turns away again; when it has turned away, the birds twitter, and when it has turned towards them they no longer twitter. And this takes place several times.

¹⁹⁰ This reconstruction has been accepted by Raios (2000: 28).

It has been recently suggested that this and other Heronian and Philonian displays involving singing birds¹⁹¹ or drinking animals¹⁹² are likely to have been used in temples because, unlike temples and other public spaces, the ἀνδρών of private houses did not have access to running water (ἐπίρρυτον ὕδωρ).¹⁹³ This suggestion is partly misleading, since it does not take into account the architectural transformations of the Roman house occurred between the third century BCE and the first century CE. Schürmann (2002: 41, 44) has argued (rightly, in my view) that Hero's hydraulic showpieces, with their emphasis on a continuous source of running water (cf. above, n. 193), seem to reflect the development of the Roman house in the Late Republic and Early Empire, when many *triclinia* either looked onto or were built in a planted garden with different water sources. It seems very tempting, therefore, to take Hero's reference to a 'cave' as a sign of the popularity of elaborated grottoes in the Roman Imperial period.¹⁹⁴

Tracing the history of ancient automata from their first mythical appearances as imaginary artefacts to their more spectacular Imperial instantiations reveals that they were used in different contexts, ranging from public occasions such as religious festivals and theatrical shows (with occasional overlaps, as in the case of Demetrius' snail) to private elite settings such as the Greek symposium and the Roman *comissatio* (with or without overtly theatrical connotations). Mainly used for entertainment, automata took the form of performance pieces or dedications (sometimes overlapping), and could also serve religious and political purposes, especially in the affirmation of economic and technological power.

¹⁹¹ Philo: *Spir.* ch. 60 (owl and birds); Hero: *Spir.* chh. 1.15 (blackcap), 2.4-5.

¹⁹² Philo: *Spir.* ch. 59 (Pan and the dragon); Hero: *Spir.* chh. 1.29-31.

¹⁹³ Bur (2016: 152, 162). Schürmann (2002: 41) notes that Pan and the dragon (*Spir.* ch. 59) is the only Philonian device which makes use of continuously running water; it is also the only one explicitly flagged for use in temples (Schürmann 1991: 223 n. 2). For running water (or lack thereof), cf. also Hero, *Spir.* 136.10 (ὕδωρ ἐπίρρυτον), 140.7 (ἐπιρρύτου ὄντος ὕδατος), 144.7-8 (μήτε ἐπιρρύτου ὄντος ὕδατος).

¹⁹⁴ On which, see Robinson (2011: 198-200).

5.4 The performative context of Hero's automata

The discussion in the previous section leads us to the question of where the automata described by Hero were used. Very few scholars have addressed this issue, and, as far as I know, in only two cases has the question of the context of use of the mobile automaton been the subject of separate investigation. In what follows, I shall discuss the context of use of the mobile and the stationary automaton separately. Before doing so, it is worth summarising briefly the positions taken by previous scholars both because they sometimes argue that the automata were used in the same context and because none of them discusses in detail the context of deployment of both automata. The following positions are mentioned in logical rather chronological order:

(1) Schürmann (1991: 190) confidently claims that both automata were used in private parties ('privaten Festen'), but she does not explain.¹⁹⁵ This argument is slightly elaborated in Schürmann (2002: 45, 53), where, however, she focuses only on the stationary automaton.¹⁹⁶ The envisaged sympotic context concerns Philo's stationary automaton rather than Hero's later version;¹⁹⁷

(2) Prou 147 suggests that, while spectacles involving mobile automata were initially performed in the theatre's orchestra, the *λογεῖον* might have provided a more appropriate performance context for Hero's mobile automaton;

(3) Bur (2016: 101) argues, on the one hand, that the mobile automaton was likely used as a paratheatrical form of entertainment at an ancient festival of Dionysus, and, on the other hand, that the stationary automaton seems more suited to a private context, either the symposium or the temple.

5.4.1 Mobile automaton

Let us start, then, by considering the performative context of the mobile automaton. As noted above, Prou asserted that the theatre's orchestra was the

¹⁹⁵ The rest of her discussion takes the form of a critical description of Hero's treatise (Schürmann 1991: 190-201).

¹⁹⁶ In the same article, she also discusses the mobile automaton (Schürmann 2002: 45-6), albeit without any direct reference to its context of use.

¹⁹⁷ Schürmann's argument is elaborated by Beacham (2013: 33) in relation to Hero's model.

place where the earliest mobile automata were displayed. There is no need to discuss the validity of this assertion both because we have seen that other public venues are attested for the Classical period – Delphi’s hippodrome from the pseudo-Socratic epistle comes to mind – and because there is no way of knowing for certain whether this was in fact the case. The premise of Prou’s assertion is the suggestion that the apotheosis of Dionysus may have been a popular subject of such representations because it would have served to harmonise the introduction of brand new (scenic) technology (that is, the mobile automata) with Dionysus’ role as the patron god of theatre. Again, we do not know whether the subject was popular, although we do know that the particular presentation of the mobile automaton was Hero’s (I.8 [6.4]). Certainly, though, Dionysus’ patronage of drama is something we should keep in mind as we proceed.

Prou’s suggestion that the mobile automaton performed its motions on the *λογεῖον* has been harshly criticised by Bur (2016: 101). Bur’s criticism revolves around two points: (1) Prou misinterprets the symbolic significance of the automaton in that he compares it to an actor (*‘un véritable acteur’*); (2) Hero’s description of the performance, with its emphasis on the repetition of movements (in particular, the double half-rotation of Dionysus), rather suggests that the automaton was completely surrounded by the audience. As for the first point, I cannot find any misinterpretation. Prou’s comparison sounds like a rhetorical exaggeration, a device not infrequent in his writing. The second point is not less problematic because, regardless of where the automaton was employed, Dionysus will not have faced all the spectators at any given time. Assuming a circular audience, only half of it will have faced the god when not in motion. Prou’s suggestion, in my view, accords well with the increasing prominence assumed by the scene building in Graeco-Roman theatres, where the *λογεῖον* could extend out to one-half of the orchestra’s radius (Kuritz 1988: 23), although some of the spectators would perhaps have been too distant to enjoy the spectacle. The weakness of Prou’s position rather lies in how he elaborates his suggestion. He imagines that the automaton travels back and forth along an L-shaped path: from the outermost thyromata to the middle of the scene, and from there to the middle of the *λογεῖον*.¹⁹⁸ This is not an instance of rectangular or

¹⁹⁸ Prou evidently had in mind an Eastern type of theatre, such as the theatres at Ephesus and Miletus (on which, see Dinsmoor 1950: 306).

circular motion, as Prou maintains, but of polygonal motion, a pattern which is only alluded to in passing by Hero. On the whole, the theatre remains a plausible context for the performance of the mobile automaton. Apart from the central role of the figure of Dionysus in the display itself, it is supported by two sets of evidence: (1) the theatrical automata I have discussed in §5.3 above (I am thinking in particular of Demetrius' snail, whose affinities with Hero's mobile automaton have been noted);¹⁹⁹ (2) Hero's own observations at II.1-2 [6.9-17] concerning, on the one hand, the properties of the ground,²⁰⁰ and, on the other, the use of a prepared trackway, which, as we have seen in §5.2 above, has recognisable parallels in earlier theatrical practice (the Hellenistic theatre at Megalopolis offers the closest parallel).

Bur's criticism of Prou's position leads her to envisage a processional context. She puts forth three possibilities (Bur 2016: 101-2): (1) the automaton was paraded on a cart (as was the statue of Nysa); (2) the automaton was brought out during the final sacrificial feast; (3) the automaton was employed during one of the pauses of the procession when specific ritual acts were performed to the accompaniment of music, singing and dance.²⁰¹ She prefers options (2) and (3) because, although option (1) has the advantage of being supported by a historical parallel, 'one cannot help but feel that the overall impact of the "miracle" of the machine would likely have been more impressive in a slightly calmer situation where all the attention was focused on this spectacular piece of technology' (Bur

¹⁹⁹ But see the caveat on the processional use of the automaton below.

²⁰⁰ Hero seems to be referring to a stone slab-paved surface (Comm. on II.1 [6.9-13]). Frederiksen (2000: 148) associates the orchestra's lack of architectural importance in the Hellenistic period with the few attempts that were made to provide the orchestra with a stone surface (e.g. theatre at Priene), further noting that '[t]here are difficulties in interpreting the "smoothed rock" orchestrai found in not a few theatres (e.g. *Argos* 2, *Korinthos* II and *Boiotian Orchomenos*); whether they were normally covered by a layer of sand or beaten earth is naturally impossible to know. Traces of such layers have been found at for example *Morgantina* and *Solous*' (for these theatres, see his Appendix at pp. 169-173). For the transition from wood to stone in the Roman amphitheatres of the Republican period, see Welch (2007: 91-4).

²⁰¹ See Kavoulaki (1999: 295), who cites the famous example of the cult regulation of the Molpoi concerning a procession from Miletus to the sanctuary of Apollo in Didyma (*LSAM* 50 = *Milet.* 1.3.133, on which see now Slawisch-Wilkinson 2018); see also Chaniotis (2011: 28). There is no mention of moments of repose in Athenaeus' text, although, according to Rice (1983: 77-8), the mixing of wine with water and its subsequent distribution to the guests in the stadium described at Ath. 200b probably occurred during one such interval. For a similar station in the procession of the Athenian Dionysia of 309/308 BCE, see X. *Eq. Mag.* 3.2, erroneously cited by Bur (2016: 102 n. 5) as X. *Eq.* 3.2.

2016: 101). Although I agree with her on this point, I do not agree that the statue of Nysa offers a historical parallel both because it was considerably larger than the figure of Dionysus – we do not know the latter's dimensions but the automaton itself was more than half the size of Nysa – and because it was in some respects a different kind of automaton (articulation, absence of rotation). Apart from size, there is another problem with a strictly processional use of the mobile automaton, that is, it would probably have taken a long time to set it up for performance, a feature the automaton shares with the stationary type.²⁰² It seems therefore possible to rule out both option (1) and option (3), unless we suppose that the automaton had been set up in a fixed location (stadium, theatre or the like) well in advance. As far as option (2) is concerned, it is perhaps worth noting that we do not know where the Grand Procession terminated. Processions usually ended at the deity's altar, where, after the sacrifice, there was a public banquet generally followed by athletic or artistic contests (Chaniotis 2011: 30-1). This may not have been the type of situation which would have allowed spectators to focus all their attention upon the automaton. Rice (1983: 35) suggested either that each of the smaller processions within the Grand Procession headed toward the altar of its own deity or, more likely, that the whole procession continued to a large assembly point. Alternatively, because no trace of a monumental altar has been found in Alexandria, it has been suggested that the final destination of the procession was the Acra or citadel of the city,²⁰³ which was probably located within the Inner Palaces of the city and where a pavilion had been designed and constructed to serve as a dining hall designated for the entertainment of royal guests (Ath. 196a-197c; Rice 1983: 31-4). This pavilion, as Athenaeus describes it, had important iconographic connections with the procession of Dionysus in terms of its decorative elements, such as columns resembling thyrsos (196c), symposia scenes featuring figures from tragedy, comedy and satyr drama (197f) and niches containing Delphic tripods (Rice 1983: 32). A context such as this is not processional in the strictest sense but in fact sympotic, and would have certainly offered a more intimate environment in which to enjoy the automatic performance. In this respect, it is certainly not

²⁰² A point made to me by Prof. Isabel Ruffell.

²⁰³ Viviers (2014: 32), followed by Bur (2016: 78). Rice (1983: 35) suggests that a temporary altar may have been set up for the occasion.

without significance that the iconography of the mobile automaton represents Dionysus as the patron of wine (wine spurting out of his σκύφος) rather than as the patron of theatre, with explicit emphasis on the god's orgiastic connotations (thyrsus, Bacchantes). Since the automaton would have needed some space to move around in different directions, it might just as easily – in fact, perhaps more easily – have appeared in outdoor spaces such as domestic gardens (compare the examples of hydraulic devices given in §5.3 above).

To sum up, two different performative contexts emerge as the most plausible for the mobile automaton. On the one hand, the evidence pertaining to the device's mobile ancestors points to public settings, first and foremost among them the theatre. This is further supported by internal evidence concerning the performance preconditions. On the other hand, the automaton would have also provided suitable entertainment at private (outdoor) banquets, where the domestic and theatrical spheres could overlap and intertwine (as with Trimalchio's dinner party). Represented as the patron of wine, Dionysus could thus reclaim and reassert his role as god of the theatre.

5.4.2 Stationary automaton

The situation is perhaps less complex in the case of the stationary automaton. Schürmann (2002: 45, 53) has convincingly suggested that Philo's stationary automaton was used as a form of entertainment in Hellenistic private symposia, where it replaced or complemented the more traditional puppet shows.²⁰⁴ The basis of her suggestion is an implicit comparison with some of Philo's hydraulic showpieces which are not in any way bound to a particular place because all that they need is a table or base on which to be positioned.²⁰⁵ Thus, she argues, Philo describes devices that are appropriate for a sympotic venue both because they do not require access to running water (for an exception, see above, n. 193) and because they do not take up much space; the stationary automaton would have

²⁰⁴ Among the examples she cites (Schürmann 2002: 37) are X. *Symp.* 4.55 (νευρόσπαστα), Ath. 19e (Πιοθεινὸς ὁ νευροσπάστης) and Hdt. 2.48 (ἀγάλματα νευρόσπαστα). But Xenophon uses the term metaphorically to describe a troupe of performance; see Huss (1997: 44; 1999: 302). I take these references from Ruffell (forthcoming 2).

²⁰⁵ See Schürmann (2002: 41 with n. 34), citing Ph. *Spir.* chh. 40-2 and 46. The stationary automaton is supported by a wooden pillar (κιδόνιον ξύλινον, XXI.1 [68.8]; cf. I.3 [2.17-18]).

fitted in the average ἀνδρών even when all the couches (up to seven in number, with a maximum of fourteen people) were occupied. I find no difficulty with this view, and considering that the Roman *triclinia* generally had only three couches each accommodating three persons,²⁰⁶ I cannot see why the automaton could not have been used in Roman banquets as well. A performative context of this type is supported by another set of considerations, which make it a much better fit for the symposium/*comissatio* than for the temple. Beacham (2013: 33), who, following in the footsteps of Formigé (1921), investigates BOOK TWO as a source of evidence for theatrical practice in the Hellenistic age, observes that such a presentation would find its ideal occasion in private Roman banquets, where, as we have seen, automata were popular and where a variety of performances took place (cf. below, n. 207). I am not sure that ‘ideal’ is the right word given that we do not know exactly what form tragic presentations took in the Imperial period.²⁰⁷ Nevertheless, I believe that the explicit theatricality of the stationary automaton is significant, and it is certainly something that would have appealed to the tastes of learned Roman banqueters. In addition to the narrative itself, which has obvious dramatic origins, I would like to recall briefly other salient connections with the domain of theatre: (1) the automaton forms a proscenium arch, with the audience facing the stage, the performance area ‘framed’ and some of the mechanisms hidden in an upper space which terminates on either side in wings (XXVIII.2-3 [100.11-102.3]);²⁰⁸ (2) the automaton displays a series of painted scenes, and takes its name (πίναξ) from the painted panels that were increasingly popular in the Hellenistic and Roman theatres (see further Comm. on I.3 [2.17-18]); (3) the device which Hero uses for producing the sound of thunder is explicitly compared with a theatrical device

²⁰⁶ Vit. 6.5.6; cf. Hor. *Sat.* 2.8.20-24 (specifying the names and position of the guests at Nasidienus’ party), with Schürmann (2002: 37 n. 13).

²⁰⁷ See Jory (1986: 150 n. 2). A wide range of private entertainments (e.g. Atellan farce, mime, comedy, story-telling, acrobatics) is attested in the sources, and is best exemplified by the broad applicability of the term *acroama* (Petr. *Sat.* 53.12, 78.5); see Horsfall (1989: 79-80, 87 nn. 53 and 61), with further references.

²⁰⁸ See Marshall (2003: 263). A triangular pediment covers the central part of the board hiding the mechanisms, and Hero notes the resemblance with a shrine; although this may have a religious significance, its primary function is to create a rational and coherent whole (ὅπως δὲ μὴ ἀλόγως ἢ σάνις ἐπικειμένη <ῆ>, ἀετὸς προστίθεται αὐτῇ καθάπερ δὴ ναῖσκη, XXVIII.3 [100.18-19]).

employed for a similar effect (XX.4 [66.10-18]);²⁰⁹ (4) the (possible) use of one or more μηχαναί, first introduced by Philo and later apparently rejected by Hero;²¹⁰ (5) the dropping backdrops which are used for scene changes (scenes two and four) – or, in one case, to bring about the dénouement of the plot (scene five) – are comparable to the Roman *siparia*;²¹¹ (6) the continuously moving scroll of papyrus used to create the illusion of movement of the ships (scene three) is similar in effect to the *scaena ductilis* (as opposed to the *scaena versilis*), a movable painted screen which could be drawn off to the side to disclose another scene behind.²¹² It goes without saying that the use of such machinery and equipment would create much the same theatricalised environment as we saw in the *Cena*. My conclusions here do not differ greatly from those reached on the performative context of the mobile automaton.

5.5 Hero's intended audience

Having established a broader context for Hero's automata, I would now like to address the question 'What was Hero's intended audience?'. In order to answer this question, we need to interrogate ourselves about the nature and purpose of the treatise. It has been said that the work belongs to what I have called the 'supergenre' of technical ekphrasis, a category which encompasses many different genres and forms. Hedylus' dedicatory epigram considered above (§5.3), to take an extreme example, describes Ctesibius' drinking-horn only from the perspective of the viewer and is far removed in both purpose and form from other works belonging to the same category such as Philo's and Biton's construction manuals on artillery engines and Hero's general introduction to the

²⁰⁹ The device used for producing thunder in the theatre was called βροντεῖον and (if we are to trust our sources, which are late and not reporting from their own experience) differed from the one described by Hero. It consisted either of a leather sack filled with pebbles which was made to collide with a bronze plate (Poll. 4.130; Schol. vet. Ar. *Nub.* 292b alpha) or of an iron container in which stones were shaken (Schol. vet. Ar. *Nub.* 292b beta); see Horst-Dieter (2003). Hero's testimony is significant because it attests to a third type of device. In my Commentary (synopsis on XIV), I have therefore used the term βροντεῖον to refer to it.

²¹⁰ See below, §5.6. On the μηχανή, see Arnott (1962: 72-8) and Newiger (1990: 34-9). A recent reconstruction of the device can be found in Chondros *et al.* (2013).

²¹¹ Beacham (2013: 31), with bibliography.

²¹² Beacham (2013: 30). On the *scaena versilis* and *scaena ductilis*, cf. Serv. *Georg.* 3.24, with Beare (1964: 284, 300); see also Bieber (1961: 74-5).

same subject, to name just a few. Roby (2016: 199-242) has investigated the relationship between description and instruction in these and other texts which include instructions for building a technical artefact, showing that the way in which an author modulates his or her authorial voice shapes the relationship between author, reader and technical object. My aim here is not to examine the instructional mode in the treatise because this would require a separate and more detailed discussion, particularly in view of the Philonian origin of the material in Book Two. However, the approach is relevant to the present topic and should be kept in mind when considering internal evidence from the work itself. So, what kind of text is the *Automata*? Murphy 2-4 emphatically argues that it is neither a complete textbook on mechanical principles (as is, for instance, the *Mechanica*) nor an instruction manual, basing the latter part of her argument on the fact that Hero frequently leaves out a number of practical details.²¹³ To illustrate this, she cites examples such as exactly how to connect a cord to the counterweight or how to prevent the cords from getting tangled up. The second example is not entirely appropriate, considering what Hero says at XXIII.8 [78.15-17]. A better example would perhaps have been the complete absence of information on the position of such elements as axles and pulleys.²¹⁴ At any rate, while it is true that the treatise does not take the form of a discussion of mechanical principles, the reader is expected to some extent to master such theoretical knowledge, one which can in many cases be acquired only through experience²¹⁵ and which is most clearly exemplified by Hero's appeal to the principle of concentric circles and his subsequent attempt at clarification by implicit reference to the principles of leverage (XVIII.3 [60.1-3], with Comm. ad loc.). On the other hand, I do not understand why the treatise should not be considered a construction manual. Roby (2016: 199-200) shows that the defining characteristic of texts providing instructions for building is the quality of 'generativity', namely, the ability to present an object as coming together before the reader's eyes. And this is

²¹³ *Contra*, Prou 139 and Berryman (2009: 140), who argue for a detailed approach.

²¹⁴ See Schmidt (1903: 276). Murphy 4 also cites the absence of dimensions for the internal moving parts of the mobile automaton, including 'the volume (not to mention the exact location) of the tube containing the millet seeds'. The tube, however, is not a moving element, and its position is specified at V.5 [22.12-13]: πρὸς ὀρθὰς κατὰ μέσον τὸ πλινθίον. On dimensions, see already above, §5.2.

²¹⁵ So Roby (2016: 267).

precisely what we see in the treatise, where instructions for constructing the two types of automaton are provided gradually and sequentially.²¹⁶

Let us return, then, to the question of audience, a topic which has already been addressed by scholars. The paucity of practical details has suggested to Murphy 4 that the treatise may have been intended for craftsmen specialised in building automata.²¹⁷ Cambiano (2011: 33) draws a similar conclusion from his examination of some of the main linguistic features of BOOK ONE. He shows that in the first part of the work, much more than in the second, Hero shows a preference for an impersonal and geometrical style similar to that of Euclid, which makes use of letter labels, third-person imperatives like ἔστω/ἔστωσαν and νοείσθω and infinitive clauses introduced by δεῖ and δεήσει.²¹⁸ In Book Two, by contrast, linguistic standardisation gives way to a more personal style that recalls Philo's instructional mode in his *Belopoeica*,²¹⁹ and in which first person singular forms abound along with frequent alternations between present, future and aorist.²²⁰ The higher degree of linguistic standardisation of BOOK ONE (indeed, the more Heronian part of the work) leads Cambiano to think of an audience consisting of craftsmen or designers (ἀρχιτέκτονες) who, as he points

²¹⁶ A gradual, sequential approach can be seen most obviously in the description of the mobile automaton, the different configurations of which are ultimately based on the same basic model. See further below, §§5.6-7.

²¹⁷ *Contra*, Marshall (2003: 267), who maintains that the tone of the treatise 'is really not so far removed from suggested hobby projects for boys found in *Popular Mechanics* over the past century'. I am not as familiar with this magazine as I probably should be. However, those familiar with it will certainly know that its mission was (and still is) to make technological topics readily comprehensible to the general public (one of its mottoes being 'Written so you can understand it'); see Seelhorst (1992: 83). This does not seem to be the case for the *Automata*, as my discussion below will show.

²¹⁸ This brings BOOK ONE closer to the other Heronian mechanical works, including the *Belopoeica*. Roby (2016: 223 with n. 117) claims that Hero's grammatical constructions and elements of his vocabulary such as third-person imperatives are characteristic of mathematical prose, an assertion she bases on a 'full corpus counts/author' information available from the TLG for the verbs of these forms used by Hero. On Hero's geometrised descriptions of his devices, see Tybjerg (2004: 46-51); see also Cuomo (2001: 163-4).

²¹⁹ On which, see Roby (2016: 210-16).

²²⁰ See Cambiano (2011: 34-5). I count a total of 50 first-person singulars in Book Two, including Schmidt's supplement at XXIV.2 [82.2]. 23 occurrences are in the present tense, 2 in the future, and 25 in the aorist. Similarly, Book Two contains 15 occurrences of the participle agreeing with the first-person singular subject, all of which are in the aorist tense and include my supplement at XXIII.5 [76.13]. In BOOK ONE, the first-person singular is replaced by the first-person plural, be it 'collaborative' or 'editorial'. For the 'editorial we', see the prefaces to both books. On the use of different verb forms in technical texts, see generally Roby (2016: 201-9), with further bibliography.

out, must have had at least a basic knowledge of geometry. This is especially true if we consider that, according to Vitruvius (*De Arch.* 1.1.3-10), the architect should ideally be trained in a curriculum which merged theory and practice and which comprised a number of disciplines including draughtsmanship, geometry and philosophy.²²¹ However, while advanced practitioners would certainly have been able to grasp Hero's explanation of circular motion in terms of a cone (ch. VIII)²²² or to interpret the diagrams which he intended to accompany the text,²²³ it does not follow that non-specialists would not have been interested in the treatise. More recently, Keenan-Jones–Ruffell–McGookin (2016: 182) have tentatively suggested that the treatise envisages a 'bifurcated audience'. Practitioners, they argue, would probably be familiar with some of the specialised terminology used throughout the treatise²²⁴ and would equally be able to fill the gaps both in Hero's own account of the automata (practical details included) and in his reasoning for taking certain design decisions. So, for example, not only does Hero not fully explain the differences between the two main axle configurations (by means of two different types of bearing, the κνώ-δαξ and the χοινικός),²²⁵ but he also leaves it to the reader to figure out why enlarging the wheels is preferable to thinning the axle in order to lengthen the automaton's journey (XVIII.3 [58.3-8]).²²⁶ Non-specialists, they go on to say, would be fascinated with the exhibition of mechanical skill as Hero expertly reveals the working of 'wonders'. After all, as is sufficiently clear from what has been said above (§5.2), he is more than interested in offering flexible templates that can be adapted and readapted for multiple arrangements, and this alone is a source of wonder and amusement even to the most inexperienced reader. The idea of a bipartite audience receives further support from Hero's own descriptive

²²¹ On this passage, see generally Anderson (1997: 5-8), and note especially Vit. 1.1.7 *item qui Ctesibii aut Archimedis et ceterorum, qui eiusdem generis praecepta conscripserunt, leget, sentire non poterit, nisi his rebus a philosophis erit institutus*.

²²² The passage has been noted as an example of Hero's flair for geometrical explanation by Cuomo (2001: 164 with n. 39).

²²³ On diagrams, see further below, §6.5. Explicit references to diagrams are found exclusively in BOOK TWO (γράφομαι: XXIII.1 [74.5], XXIV.2 [80.15]; ὑπογράφωμαι: XXVII.2 [98.12]), although the use of letter labels is a clear pointer to the role of illustrations.

²²⁴ Specialised words occurring in BOOK ONE are discussed in the appropriate places in the Commentary. For an index of technical terms, see **Appendix 6**.

²²⁵ Keenan-Jones–Ruffell–McGookin (2016: 182). See further below, §5.6.1 and Comm on II.3 [8.5-7].

²²⁶ Unless perhaps we place a lacuna after XVIII.3 [58.7] περιφέρεια.

strategy. As noted by Roby (2016: 146), Hero pays great attention to what a spectator would see and that requires him to shift imaginatively from the description of the device's interior to the description of its exterior. On the one hand, then, he repeatedly lays emphasis on the need to hide the mechanisms.²²⁷ On the other hand, he invites the reader to assume the position of the hypothetical viewer, appealing not just to sight but also to the senses of touch and hearing.²²⁸ It is perhaps no coincidence that this two-pronged strategy is implicitly foregrounded in the opening statement of the treatise, where, as we have seen, Hero juxtaposes the perspectives of the craftsman (δημιουργία) and of the spectator (θεωρία).

In summary, the treatise – no doubt an instruction manual on the construction of automata – seems to have been intended both for specialist practitioners and non-specialists. The former would have had to rely on their practical and theoretical knowledge to make full use of Hero's incomplete instructions. The latter would have focused their attention on the wondrous aspects of the work, in some cases possibly motivated by a desire to further their understanding of the complex art of making automata.

5.6 Hero and his sources

In composing his works, Hero drew freely on a variety of sources, including, but not limited to, his mechanical predecessors. The mechanician Ctesibius was one of his sources, as suggested by the title under which his treatise on artillery has been transmitted (*Ἡρώνης Κτησιβίου Βελοποιικά*).²²⁹ As a matter of fact, Hero's *Belopoeica* deals with early third-century BCE models, and Philo, in his homonymous treatise, describes two artillery inventions by Ctesibius that used bronze springs (χαλκέντονον) or compressed air (ἀερότονος καταπάλης) rather

²²⁷ Hero's insistence on the concealment of cords is a paradigmatic example (XIII.9 [50.14-15], XVII.1 [56.11-12], XVII.2 [56.21-22], XXX.4 [108.5-6]), but there are many other examples: XIII.7 [48.11-13], XXIII.2 [74.11-12], XXVI.5 [94.2-4], XXVIII.1 [100.12-17], XXX.6 [110.4-6]; cf. XV.2 [52.14] and XXVIII.5 [102.21-22].

²²⁸ A point I elaborate in my discussion of Hero's notion of ποικιλία (Comm. on I.1 [2.4-5]); cf. also Comm. on I.5 [4.12-14].

²²⁹ On the close dependence of Hero's *Belopoeica* on Ctesibius' lost writings, see Marsden (1969: 3).

than the traditional springs made of twisted sinew or hair.²³⁰ The *Pneumatica*, as will become clearer later, comes from far more diverse sources. If we limit ourselves to the main written sources, we know that 15 out of the 80 devices described in the work are taken from Philo (albeit usually modified) and that two chapters, *Spir.* 2.17 (cupping instrument) and 2.18 (pus extractor), appear to derive from some surgical book.²³¹ In the introductory section of the treatise, moreover, Hero not only quotes almost *verbatim* the third-century BCE philosopher Strato of Lampsacus (*Spir.* 24.20-26.8)²³² but also appeals to different theories to explain rarefaction effects.²³³ Similarly, the *Mechanica* contains traces of three now-lost works by Archimedes devoted, respectively, to centres of gravity (*Mech.* 1.24), upright supports (*Mech.* 1.25-8, 30-1 and 2.35-41) and balances (*Mech.* 1.33-4).²³⁴

When considering Hero's (use of) sources in the *Automata*, we need to consider separately the whole work and the parts into which it falls. Let us first look at the individual books.

In BOOK TWO, Hero explicitly refers to Philo as his source, stating that the latter's work far surpassed that of other, unspecified predecessors (XX.1 [64.8-10]). Hero's aim is to improve the Philonian model, which in turn drew on pre-existing (Ctesibian?) technology.²³⁵ Whether Ctesibius was Philo's source is doubtful, but, as we have seen in §5.3 above, he certainly had constructed (water-powered) automata. Hero claims (whether explicitly or implicitly) to have improved Philo's model in two ways: by replacing the *μηχανή* used for the appearance of Athena with a hinged device (on which, see above, §5.2) and by

²³⁰ These experimental models, the former of which was greatly improved by Philo (cf. *Bel.* 67.28-68.1), are described at *Ph. Bel.* 69.31-72.4 and 77.9-78.22, respectively; for discussion, see Marsden (1969: 5-7, 41, 168) and, more recently, Schiefsky (2015: 640-9).

²³¹ See Drachmann (1948: 80-1, 100, 126). Fraser (1972: 1.431 with n. 450), *contra*, finds it likely that Ctesibius' lost works on pneumatics served as a source not only for Philo but also for Hero (an opinion misattributed to Diels 1893: 110 n. 3). According to Diels (1893: 106-7), Hero would have reworked Philo's *Pneumatica*, which in turn depended on Ctesibius; see Drachmann (1948: 90-1), who is inclined to assign to Ctesibius, rather than to Strato of Lampsacus, the experiments supporting the latter's view of the void in the introduction to Hero's *Pneumatica*.

²³² This passage appears almost *verbatim* in *Simp. in Ph.* 693.11-18, quoting Strato.

²³³ I cannot discuss here Diels' (1893) untenable attribution of the introduction of the *Pneumatica* to Strato, but instead refer the reader to the recent contributions of Berryman (2009: 166-70; 2011). For Hero's reference to Archimedes' *Floating Bodies*, see above, n. 109.

²³⁴ Drachmann (1963b).

²³⁵ That Philo drew on Ctesibius is presumed by Ruffell (2016).

showing how to produce the sound of thunder and to strike Ajax with lightning (the descriptions of the latter effects were apparently accidentally left out by Philo; XX.2-4 [64.12-66.10]).²³⁶ Despite his intentions, Hero elsewhere makes mention of a μηχανή (XXII.6 [72.20], XXVIII.2 [100.15], XXVIII.3 [102.2-3]^{bis}), which can hardly refer to any other machine than Athena's (but cf. the more generic reference to μηχαναί outside the πίναξ at XXI.2 [68.15-16]). This contradiction has led Schöne (1891: 77) to tentatively suppose that the main part ('Haupttheil') of the book was derived *verbatim* from Philo and that Hero failed to remove all unnecessary references to the μηχανή. This suggestion tends to be confirmed by the linguistic and stylistic differences found between the two books (cf. above, §5.5). At any rate, Hero (XXII.2-3 [70.14-18]) makes it explicit that he relies on technological advances of his time when, after noting the superiority of his contemporaries over the ancients, he goes on to describe the Nauplius arrangement (τοῦ δοκοῦντός μοι κρείττονος, with which cf. XXI.2 [68.18-19]). In Book Two, therefore, Hero's novelty consists more in providing an updated presentation of earlier material than in the technical improvements themselves,²³⁷ as he himself programmatically proclaims at XX.5 [66.22-68.3].²³⁸

The situation is less clear-cut in BOOK ONE, although there is no doubt more scope for innovation. Here, too, Hero refers to his predecessors on a

²³⁶ Apparently, Hero was able to consult several 'copies' (συντάγματα, XX.3 [66.5]) of Philo's work; see Ferrari (1985: 266) and, more dubiously, Cambiano (2011: 26). For another (non-claimed) Heronian improvement, see below, §5.6.3.

²³⁷ Along somewhat similar lines, Cambiano (2011: 25) misleadingly argues that the novelty lies primarily in the account Hero gives of contemporary state-of-the-art technology. His argument fails to take into account the extent to which Hero depends on Philo, who receives high praise for his achievements (XX.5 [66.19-22]). Tybjerg (2005: 210-13), by contrast, seems to extend my claim to Hero's originality *tout court*, although she draws inconsistent and contradictory conclusions. A detailed treatment of Tybjerg's argument falls outside the scope of the present discussion, and I must confine myself to a few remarks on the *Automata*; see below, n. 238.

²³⁸ In commenting on this passage, Tybjerg (2005: 211) infers that the novelty of Hero's presentation relies on his ability to *compare* and correct pre-existing material, which in turn leads her to interpret the adjective καινότερος (XX.1 [64.8]) as referring not only to the technical inventions described in the book but also to the account itself. There are at least two problems here. First, there is no firm evidence that any of the devices presented in BOOK TWO is Hero's own invention. Second, Tybjerg's inference is incorrect, based as it is on an erroneous translation of the participle τὰ παραθεωρηθέντα, which should be understood as 'what has been overlooked' ('le cose trascurate', Baldi 32^v; cf. Schmidt 407) rather than as 'comparisons' (Murphy 28). Indeed, Hero does not compare different devices, but he makes improvements and additions.

number of occasions, and some of his references likewise serve the double purpose of justifying his work as being part of an established tradition and emphasising the novelty of his contribution (see Cambiano 2011: 24). So, while predecessors play a central role in presenting automata-making as a worthy subject of study (I.1 [2.3-4]),²³⁹ Hero later criticises them rather harshly. Hero's criticism revolves around two interconnected issues: the aesthetic appeal of the mobile automaton and the technical effectiveness of the construction techniques. The reason for refusing scenic arrangements of earlier times (II.12 [14.11]) is that the methods used by the ancients were not advanced enough to allow practitioners to achieve aesthetically satisfying results. This becomes evident when we compare Hero's remarks on the replicability of methods (II.12 [14.12-14]; cf. Comm. ad loc.) with V.1 [20.8-12]. His predecessors, says Hero, have handed down (παρέδωκαν) a system of moving the automaton back and forth along a straight line, but this has often proved unsuccessful owing to methods (αἱ ὑπ' αὐτῶν ἀναγεγραμμέναι μεθόδοι, cf. XX.1 [64.5]) that not only were unreliable but also could not stand up to systematic empirical testing. Hero does not specify who his predecessors are, but he does refer to a tradition that by his time had already been codified in written form. This seems precisely the kind of tradition to which Vitruvius refers in *De Arch.* 7 *praef.* 14, where he gives a list of Greek writers on machinery (*de machinationibus*) that includes Ctesibius and Philo. The improvement of earlier methods permits Hero not only to provide a fresher-looking device (καινότερον... κατασκευάσμα, II.12 [14.12]) but also to perfect and extend its mechanisms of movement.²⁴⁰ In addition to providing a safer mechanism for straight-line motion, Hero claims to have introduced more complex patterns of movement such as circular and rectangular (V.2 [20.13-17]).²⁴¹ He later (XI.1 [36.1-5]) introduces the possibility of moving the automaton in other ways, too, namely, along a non-rectangular polygonal track

²³⁹ See above, §5.2.

²⁴⁰ I borrow the concept of 'mechanisms of movement' from McCourt (2012: 187), who uses it as a reference to the mechanical configurations adopted for moving the automaton locally from place to place.

²⁴¹ McCourt (2012: 193) erroneously calls the latter 'rectilinear movement', adding that the automaton travels along the sides of a 'rectilinear form'. Hero unmistakably refers not to any rectilinear figure (εὐθύγραμμον σχῆμα) but to a rectangular polygon (παραλληλόγραμμον ὀρθογώνιον). On rectilinear figures, see Comm. on XI.1 [36.1-3].

and in a snake-like pattern.²⁴² A comparison with the *Pneumatica* seems to suggest that at least the first of these patterns of movement represents a Heronian innovation.

Apart from the sources mentioned above, we have no way of knowing exactly what material Hero used in compiling his *Pneumatica*. Drachmann (1948: 81-2) posited a number of different sources, ranging from books to actual instruments. He found confirmation of Hero's eclectic and varied use of sources in the fact that there are some differences in the wording of the headings of the chapters (Drachmann 1948: 82-4). He identified five different openings, which may occasionally occur within, rather than at the beginning of, chapters. OPENING A, introduced by connecting formulae, characterises completely revised chapters but gives no hint of the underlying sources. OPENING B, corresponding to Ἐπὶ τινῶν, etc. or Ἐνία τῶν, etc., indicates descriptions of familiar devices, often improved by Hero. OPENING C, namely genitive absolute followed by future indicative or present infinitive, together with OPENING D, which begins with κατασκευή/κατασκευάζεται or the like, introduces either a well-known device or an invention by Hero. Finally, OPENING E, which comprises variations on the foregoing, indicates an improvement made by Hero; it may be introduced by expressions like Δύναται δὲ καὶ ἄλλως, etc. or, exceptionally, by Ἐὰν δὲ βουλόμεθα, etc. (*Spir.* 128.5).²⁴³ Drachmann's review of the chapter headings of the *Pneumatica* led me to examine the *Automata*, and I have found that some sections throughout the text begin with OPENING A, OPENING D and OPENING E, or, at least, with variations thereof. Before reviewing these openings, let me make two points. The first point (a methodological one) is that Drachmann's model does not apply to the *Automata* in exactly the same way as it does to the *Pneumatica*, because, while in the latter case chapters are devoted to individual instruments, in our case the text has a less rigid structure. This is particularly obvious in the case of OPENING A, but, nonetheless, the nature of the inferences involved is essentially the same. The second point (a more specific one) is that three passages begin with what could be argued to be OPENING C. These are XI.11 [42.4-7], XXVIII.1 [100.5-7] and

²⁴² Pace Cambiano (2011: 33), who takes the whole section to refer to snake-like motion.

²⁴³ Other possible variations are Ἔστι δὲ καὶ ἄλλως, etc. (*Spir.* 140.7 and 178.27), Καὶ ἄλλως, etc. (*Spir.* 218.13) and δέον, etc. (*Spir.* 148.6 and 302.10). I take the last two references from Drachmann (1948: 83).

XXIX.1 [104.14-15]. In none of these cases does the phrasing (genitive absolute + future indicative) introduce the description of a device or configuration. And even though XI.11 [42.4-7] refers generally to an improvement made by Hero, the shared presence of a connective discourages identification with OPENING C. Let me now, then, review the openings:

(A) Connecting formulae occur quite consistently throughout the text, with a preponderance in BOOK ONE. Overall, OPENING A occurs 65 times, of which 39 times in BOOK ONE and 26 times in BOOK TWO. These figures take into account occurrences of *δὲ καὶ/δὲ...καί*, excluding those appearing in OPENING E, of *μὲν οὖν* and of *οὖν καί*, as well as occurrences of *δέ* at (or near) the beginning of the chapter. For the editorial implications of the distribution of connecting formulae,²⁴⁴ see below, §5.7.

OPENING A, for instance, introduces the descriptions of backward motion (VI.1 [22.21]), circular motion (VII.1 [26.6]) and rectangular motion (IX.1 [30.3]). The descriptions of the piping system (XIII.2 [44.17]), of how the Bacchantes dance (XVI.1 [54.9-10]) and the cords are concealed (XVII.1 [56.12-13]) all begin in the same way (*γίνεται οὖν καὶ τοῦτο οὕτως*), with which cf. especially XIV.1 [50.17-18]. The same pattern (*ποιήσομεν οὖν καὶ...οὕτως*) is followed by XXVI.1 [90.10] and XXVIII.2 [100.11], although in the latter case the true beginning is XXVIII.2 [102.3-4]; see below.

(D) There is only one occurrence of OPENING D, XXVIII.2 [102.3-4], which introduces the description of Nauplius' torch: *ἡ τοῦ πυρσοῦ γίνεται κατασκευὴ τοιαύτη οὕσα*. The basic version of the device is clearly an instrument in common use, as confirmed by XXVIII.6 [104.2-4]. The phrase found at I.2 [2.9-10], *κατασκευάζονται ναοὶ ἢ βωμοί*, must not be classed here; the verb only refers generally to the process of construction, as it does at II.2 [6.18] and XXIII.1 [74.5].

(E) Overall, there seem to be eight instances of OPENING E, of which four occur in an explicit form. One chapter, dealing with the two-counterweight system, begins with *Δύναται δὲ καὶ ἄλλως*, etc. (XIX.1 [60.10]). XI.1 [36.1] has a slight variation (*Δυνατὸν δέ ἐστι καὶ ἄλλως*, etc.), which concerns the

²⁴⁴ My interest in such implications led me to adopt a looser criterion for classifying occurrences of OPENING A. For this reason, I have included occurrences that do not introduce descriptions of instruments or configurations.

possibility of effecting polygonal motion. The immediately following clause builds directly upon it, and relates to snake-like motion (ἔτι δὲ καὶ... δυνατόν ἐστὶ, XI.1 [36.3-4]). The explanation of how the mobile automaton makes a pause starts with ἐὰν δὲ βουλώμεθα (VI.2 [24.9]), which is incrementally varied to introduce repeated forward and backward motion (ἐὰν δὲ καὶ... βουλώμεθα, VI.3 [24.16]). To these instances we may add XIV.2 [52.3], XX.2 [64.15] and XXVIII.6 [102.23].

This review sheds some light on the presence of alternative, apparently incompatible versions of mechanisms. These have generally been explained by having recourse to assumptions of interpolation, but unnecessarily so. In what follows, I will discuss three instances of this phenomenon, referring the reader to the Commentary on BOOK ONE when appropriate.

5.6.1 Snake-like motion

In ch. XI, Hero presents three configurations for achieving snake-like motion. McCourt (2012: 194), who discusses in some detail most of Hero's mechanisms of movement, does not acknowledge the presence of these alternative versions; moreover, he misunderstands the first configuration, claiming that it allows for 'all patterns of movement'. This seems due to the fact that, as we have seen above, Hero starts off by suggesting the possibility of polygonal motion. But nowhere else in the rest of the chapter does he connect any of his configurations with other patterns of movement. The presence of three distinct configurations is a clear indication of multiple layers in the mobile automaton, although without explicit attribution. The fact that Hero begins his account with what I have classed as a variation of OPENING E seems to suggest that we are dealing with one of his improvements, unless we are to suppose that he is silently appropriating, in part at least, earlier (Philonian?) material. The latter possibility is very tempting indeed, especially since Hero ends up preferring the third configuration, where the hubs (χοινικίδες) are replaced by pivots (κνώδακες) and the front axle is replaced by two independent axles. It may well be, then, that the first and the second configurations do not represent genuine Heronian improvements. And even if Hero had in fact modified the first configuration (with the front wheels mounted on separate rotating hubs and the rear wheel

turning on pivots), adding a third hub and fixing the rear axle to the base of the automaton would have been the easiest, most natural thing to do. Certainly, Hero recognises that the hubs do not rotate effectively, and expresses his insight into the greater efficiency of the κνώδαξ (XI.8 [40.3-7]). Hero's use of the impersonal form ἀρέσκει in this context recalls a similar idiom in Ath. Mech. 33.5 and 35.4, where the phrase Ἀρέσκει δέ μοι, etc. introduces two technological innovations: the forewheel (πρότροχος) for tortoises and other stone-throwing machines and the goblet-jointed crane (where the element of innovation consists in the combination of the goblet-joint, χαρχήσιον, and the crane, γέρανος).²⁴⁵ This somewhat parallel usage lends further support to the idea that the third configuration belongs to Hero. For more on snake-like motion, including discussion of Schmidt's interpolations, see Comm. ad loc.

5.6.2 Two-counterweight system

In ch. XIX, Hero discusses an alternative system for bringing about motion in the mobile automaton. Instead of having only one counterweight, the automaton now has two counterweights, one bringing about forward and backward motion, the other all those movements that do not have to do with locomotion (αἱ δὲ ἐκτὸς τῆς πορείας κινήσεις, I.8 [12.3-4]). Each counterweight is located in a separate tube, which is nothing other than a section of the previously undivided σύριγξ. The whole chapter has been deemed an interpolation by Olivieri (1901: 431-2). Olivieri's main point is that the chapter does not constitute an alternative explanation of how movements are effected, but rather a failed attempt to fill a lacuna in the text. What is missing, he argues, is the explanation of how the movements other than locomotion succeed one another. The chapter, which Olivieri regards as unrelated to the preceding sections (XVII.3-XVIII), would thus provide only limited information on the connection between forward and backward motion and all the other movements. Olivieri's argument rests on two misconceptions: (1) that ἄλλως (XIX.1 [60.10]) is out of context (he considers

²⁴⁵ See Whitehead-Blyth (2004: 36). I cannot agree with these scholars that Hero and Athenaeus use the 'same idiom' ('I am in favour', p. 38). As already noted by Whitehead-Blyth (2004: 38 n. 93), Hero uses the impersonal form ἀρέσκει only once elsewhere (*Spir.* 4.11), where, however, it refers to the 'generalised agreement' among ancient physicists on the composition of air; on the impersonal use of the verb, see generally LSJ s.v. ἀρέσκω s.v. IV.

the term 'strano e sintomatico', p. 431); (2) that the marginal note found at the end of almost all manuscripts (λείπει) indicates a lacuna occurring in BOOK ONE. As far as these two points are concerned, Schmidt (1903: 277-8) notes that in ch. XIX the movements are presented as occurring in a different way than before (namely, by means of two counterweights) and that λείπει can only indicate a lacuna at the end of the treatise (cf. already above, n. 147). This is certainly correct, but there is no reason to presume that, because the mobile automaton features two distinct types of movement, the two-counterweight system represents the oldest version of the device.²⁴⁶ From what has been said so far, it is fairly clear that Hero is adapting at least one prior version of the automaton, and that the version handed down to him by his predecessors is the one featuring a single counterweight. Furthermore, as we have seen, ch. XIX begins with OPENING E, which does not merely argue against interpolation but indeed suggests that the two-counterweight system is Hero's own improvement. If so, then, why does Hero seem to prefer the single-counterweight system? There are, I think, at least two non-mutually exclusive ways of answering this question. The first way is to assume that the improved model was still in an experimental phase at the time of Hero's writing. This would have probably meant that it had not yet been further adapted to incorporate configurations for more complex patterns of movement. The second way is to deny downright that Hero prefers either system. The most logical thing for him to do was to adopt only one system (the oldest one) and progressively adapt it to various forms of motion. Describing the two-counterweight system earlier on would have, at least to some extent, disrupted the narrative, and so Hero relegated his description to the end of the book. Was Olivieri right, then, in assuming that the chapter has no connection with what precedes? Schmidt (1903: 277-8) suggests, rather cryptically, that the connection between XVII.3-XVIII and ch. XIX lies in the fact that the locomotion of the automaton is still brought about by means of a single counterweight. While this is true as far as it goes, it overlooks the purpose of XVII.3-XVIII.2. There Hero proposes three alternative modifications to the basic configuration of the automaton, which would, at least in theory, lengthen

²⁴⁶ A belief held by Schmidt (1903: 278).

the distance travelled.²⁴⁷ A tube containing two counterweights would have meant a double length of cord connected to the wheel axle, and that would have increased the range of motion. The two-counterweight system, therefore, does not represent *sic et simpliciter* an alternative to the single-counterweight system, but rather an improvement on the potentially unsuccessful modifications described in the preceding context. It does, in other words, find its natural place in ch. XIX.

5.6.3 Nauplius' torch

In ch. XXVIII, Hero deals mainly with the construction and operation of Nauplius' torch. The device consists essentially of a bronze chest containing a lighted lamp. The chest is initially described as lidless (πῶμα μὴ ἔχον, ἀλλὰ ἀχανές, XXVIII.3 [102.5]), but later as equipped with a triangular bronze plate (ἄλλῳ δὲ λεπιδίῳ... καταπωμάζομεν τὴν ὀπὴν, XXVIII.5 [102.15-16]). This second version of the device, where wood shavings are used as a combustible, recalls the mechanism used to light the fire on the altar of Dionysus in the mobile automaton (XII.2-4 [42.16-44.11]). Hero may have this in mind when he speaks of 'another' plate. Before explaining how the plate is moved mechanically, Hero proposes equipping it with a wooden peg: καὶ γὰρ ξύλινον ἐπιούριον ἔξει, ἐὰν βουλώμεθα τελείως πάντοθεν πωμάσαντες ἀόρατον ποιῆσαι τὴν φλόγα (XXVIII.6 [102.23-24]). Schmidt LXIII found these words suspicious, and tentatively suggested (app. crit. to 444.4) either replacing ἐπιούριον with κλειθρίον or deleting the whole passage. His main reasons for suspecting interpolation are as follows: (1) the peg is made of wood, unlike the rest of the chest; (2) there is a contradiction with XXVIII.3 [102.5];²⁴⁸ (3) capping the lamp means that the flame goes out when oxygen is exhausted. As to the peg, Schmidt no doubt fears that it would catch fire (cf. below, n. 250). If we follow Prou 241 n. q, however, the flame of the lamp is covered by the surface near the base of the plate, which, by absorbing the heat of the flame, would prevent the shavings from catching fire owing to overheating. It is thus unlikely

²⁴⁷ For details concerning the impracticality of these modifications, see synopsis on XVII.3-XVIII.

²⁴⁸ I cannot infer from Hero's words that the chest is open on the back side ('nach hinten').

that the peg, driven through the extremity opposite the base,²⁴⁹ would start burning. To this we should probably add that Schmidt's proposed emendation is pointless – and this not only because a κλειθρίον ('slide') would still be made of wood but above all because it could not act as a pivot point for the rotation of the plate.²⁵⁰ As regards the second point, there is no contradiction here. At first glance, there seems to be a contradiction between XXVIII.3 [102.5] and XXVIII.5 [102.15-16], but, as we shall see, it is only apparent. Moreover, the fact that the passage contains a conditional clause introduced by a slight variation of OPENING E leads us to think that the capping of the lamp is an improvement made by Hero. Finally, with respect to the threat posed by oxygen exhaustion, we note that Hero only intends to conceal the flame. He does not say anywhere that the plate is airtight. When he instructs the reader to cut out an aperture in the upper side of the chest (XXVIII.4 [102.9-10]),²⁵¹ he does not say what shape it should be, and nothing compels us to believe that it is shaped to match the plate. All in all, Schmidt's arguments are at best inconclusive, and it seems unnecessary to resort to interpolation to explain the apparently contradictory elements of the text. The reasons for this claim will become clear in the following section.

5.7 Status of the text

The question of the status of the text is intimately connected with Hero's relationship to his sources. Once again, a comparison with the *Pneumatica* is instructive. Drachmann (1948: 79-80) has convincingly hypothesised that the *Pneumatica*, as we now have it, is Hero's posthumously published notebook. In his view, the introduction and the first eight chapters, all of which begin with OPENING A, represent either Hero's own manuscript or a rough draft for the beginning of the work, whereas the remaining chapters would be his material in

²⁴⁹ At least according to Prou's reconstruction; but cf. also Schmidt 444 Fig. 107b. The peg is instead missing in Murphy 37 Fig. 13.

²⁵⁰ Schmidt 445 n. 1 does not betray the slightest awareness of the problematic nature of his conjecture, which he supports by citing XIX.2 [62.1]. That the ignitability of wood represented a concern for the scholar is confirmed by the fact that he suggests, as an alternative to a κλειθρίον, a 'Klappe aus bronze'. On Hero's κλειθρίον, mainly designating the lock mechanism of the σύριγξ, see Comm. on IX.5 [32.8-9].

²⁵¹ This, too, apparently contradicts the claim that the chest is 'wide open'.

the form of more or less finished notes. Drachmann's hypothesis explains not only the disorderly arrangement of the material but also various inconsistencies such as the absence of letter labels in certain descriptions. One of the most interesting examples he cites of the latter is *Spir.* ch. 2.34, which contains two slightly different descriptions of the same instrument (the so-called *miliarium*, a water-heating device), one with and the other without letter labels.²⁵²

Let us proceed, then, on the assumption that Hero did not complete his revision of the *Automata* and see whether it fits with, and justifies, the status of the text. This assumption would in effect explain the following:

(a) The references to topics not discussed anywhere in the treatise, such as II.6 [10.8] and III.2 [16.10];

(b) Some digressions or apparently misplaced material, such as XII.3 [44.1-2] and XXVIII.2-3 [100.11-102.3];

(c) The disorderly or discontinuous arrangement of the material such as occurs, for example, in XII.2-4 [42.14-44.11] and XIII.2-7 [44.17-48.13];

(d) The contradiction concerning the appearance of Athena, who is also described as being painted on the cloth background at XXVIII.1 [100.7-8];

(e) The contradiction(s) concerning Nauplius' torch;

(f) The (partial) repetition or duplication of the information such as occurs at XII.4 [44.7-9], XXVIII.3 [102.3-4] and XXVIII.4 [102.14];

(g) The complete absence of letter labels in some descriptions, such as XIV.1-2 [50.18-52.6], XX.4 [66.10-18], XXV.2-6 [84.15-88.14], XXIX.1-2 [104.19-106.3] and XXX.1-6 [106.7-110.10]. It is interesting to note that three of the four passages from BOOK TWO contain genuine Heronian descriptions;²⁵³

(h) The clear-cut bipartite structure of ch. XXVI, where we first find a description without letter labels, mainly dealing with constructional details, and then a short, badly corrupt description with letter labels, explaining the associated configuration. The first description may have been taken directly

²⁵² Drachmann (1948: 80) regards the first description (*Spir.* 304.10-3) either as something copied from some book or as notes taken directly from the device, although he later (p. 131) opts for the latter option; the second description (*Spir.* 310.3-316.13), on the other hand, seems to have been intended for publication.

²⁵³ Sound of thunder (XX.4 [66.10-18]); appearance of Athena (XXIX.1-2 [104.19-106.3]); disappearance of Ajax (XXX.1-6 [106.7-110.10]). See above, §5.6.

from Philo, whereas the second description may have been either added or, more likely, edited by Hero.²⁵⁴

Drachmann (1948: 80) finds confirmation of his hypothesis, *e contrario*, in the fact that whenever Hero describes two devices, of which one is a clear improvement on the other, the original version always comes first. The situation is not different in the case of the *Automata*. We have seen that Hero presents multiple configurations, and that he does so in a progressive fashion. The three configurations for snake-like motion, for instance, follow naturally from each other just as the two-counterweight system follows from the less reliable mechanisms for increasing the range. Similarly, Hero's own version of Nauplius' torch comes after the first (presumably Philonian) version of the device, as also happens in the case of the sounding devices described in ch. XIV (see synopsis ad loc.).

The hypothesis that the *Automata* was published (perhaps posthumously) in an incompletely revised form has clear advantages. It enables us to avoid the vicious circles involved in certain assumptions of interpolation. It enables us to avoid interpreting the lack of details or follow-up information as an indication of the incompleteness of the text.²⁵⁵ It enables us to correlate the distribution of connecting formulae with the processes of authorial revision and thereby to confirm that BOOK ONE had been revised to a greater extent than BOOK TWO (which, indeed, shows a higher degree of internal incoherence). Overall, it enables us to see the text in a new light, one which accords best with Hero's actual use of sources.

²⁵⁴ A similar, but less clear-cut, bipartite structure occurs in ch. XXVII. It is not until the end of ch. XXVIII that the components of Nauplius' torch are mapped onto points in the diagram (XXVIII.7 [104.11-13]; cf. **Fig. 25**). I have two reasons for deleting these words: (1) the mention of knobs is out of place (see already Schmidt 447 n. 1); (2) the neuter article is repeatedly used with non-neuter nouns.

²⁵⁵ A distinction must be made between incompleteness of the text and incomplete authorial editing. The fact that Hero failed to complete his revisions, for reasons unknown to us, does not necessarily imply that he considered the work to be incomplete. I regard the *Automata* as complete in its internal structure, and take the references to content not found anywhere in the text as due either to incomplete revision or to textual lacunae.

6. PRINCIPLES AND CRITERIA

6.1 Text

The *constitutio textus* owes much to the work of the previous editor, although divergences are not at all rare. Compared to Schmidt, I take a bolder yet more consistent approach to conjectural emendation, while retaining manuscript readings wherever possible. All text-critical decisions have been driven by the concern to offer a text as close as possible to the original. For this purpose, I took into account Hero's style and vocabulary, as well as statistical and contextual considerations. Palaeographical aspects played a role as well, and the reader will find evidence of this in the Commentary. Textually, BOOK TWO represents a more difficult challenge for the modern critic than BOOK ONE, and it is certainly regrettable that, within the confines of this work, it was not possible to provide a commentary on the whole treatise. Nevertheless, although the precise extent of Hero's debt to Philo is unknown, the usage of the latter author has been consistently taken into account as part of the text-critical process. Comparison with Philonian material proved particularly instructive wherever Heronian evidence was scarce or absent.

The formatting and layout of the text follows as far as possible manuscript practice. I have adopted the chapter divisions which appear in the main manuscripts, but, for the sake of convenience, I have accepted the additions made by Schmidt and Haase (cf. above, §5.1). Similarly, in order to avoid introducing a new system of internal division, I have employed Schmidt's subdivisions without altering the consecutive numbering of chapters and sections. Internal paragraphing more faithfully reflects that of the manuscripts, in particular **T** and – in places where the latter is no longer extant (VII.1 [26.7] and XIX.1 [60.12]) – its closely related manuscript **Eb**. In two cases, I have followed **AGM** (XXIV.2 [80.14]) and **M** alone (XXVI.1 [90.10]). However, in order to achieve consistency with other chapter openings of BOOK TWO, I have

preferred not to indent XXV.1 [84.12] and XXVI.1 [90.6], both of which are marked off (with an L-shaped sign) in **M**.²⁵⁶

Spelling has been normalised throughout.²⁵⁷ Capitalisation has been preserved as found in the manuscripts, except in the case of personal names, which are always capitalised. Unlike in the previous edition, letter labels have been reproduced as they appear in the manuscripts: lower case and overlined. The following spelling and accentuation errors were overlooked by Schmidt: καταπρόσθεν and/or the further corruption κατὰ πρόσθεν (inexplicably printed by Schmidt) for κατάπροσθεν;²⁵⁸ τρόχιλος/-ον for τροχίλος/-ον, where the former is attested much more frequently in later times (from Oribasius onwards), and which I have silently corrected at VI.4 [26.3] and XXIV.5 [84.3]; χερίον/-α for χέριον/-α.

Punctuation presents a different set of issues and problems. Thévenot's (and, to a slightly lesser extent, Prou's) punctuation is, on the whole, confusing and unhelpful, because, apparently, it is based on the manuscript punctuation, which is often haphazard and erratic. The punctuation of Schmidt's edition is much more accurate and systematic, although it is not always clear when he is following the manuscripts and when he is supplying his own punctuation (in his apparatus criticus he does not record deviations from the main manuscripts, nor does he provide a statement of practice elsewhere). I have therefore chiefly adopted his punctuation, deviating from it where a different punctuation either accords better with my understanding of the text (see, for instance, XXIV.2 [80.12]) or improves its readability and consistency (see, for instance, XXII.5 [72.12]).

²⁵⁶ In the former case, the sign is most probably intended to indicate the place where the text resumes its normal order. The tilted obelus (∕) found in the same place in the lower margin of **A** seems to serve the same purpose, for a similar sign occurs at the beginning of the reiterated passage from XXII.6; see above, n. 84.

²⁵⁷ For instance, abbreviations and ligatures have been expanded, and the shape of pi, which in some manuscripts is realised in cursive as π, has been rendered as π.

²⁵⁸ This adverb is attested elsewhere only thrice in the Delian inscriptions: *IG* 11.2.161 A 45, 165.22 and 23; cf. 163 A fr. a-f 51 (κατάπροσθε); Le Roy (1973: 278 n. 54).

6.2 Apparatus criticus

The apparatus criticus has been composed in the positive way, except in the following cases: (1) when a negative entry does not cause inconvenience, confusion or obscurity (for instance II.9 [12.10]); (2) when I record deviations from Schmidt's punctuation (for instances, cf. above, §6.1). As a rule, I have not recorded orthographic errors and variants when they do not alter the meaning of the transmitted text.

6.3 Translation

As has been seen in §2.2 above, the most recent complete translations of the treatise are not unproblematic, particularly with respect to transparency and faithfulness to the text. Moreover, Murphy's English translation is not easily accessible, and readers are still more likely to derive greater benefit from Schmidt's older translation into German. In my English translation I have attempted to adhere as closely as possible to the original text while at the same time aiming at clarity, literary quality and readability. I have tried to convey Hero's stylistic features as much as possible, although on the whole I have prioritised accuracy over style. This proved particularly important in the case of an author like Hero, who intertwines different discourses and domains (to wit, mathematics, technology, theatre, architecture and philosophy) and who deliberately deploys technical language. The reader should therefore not be amazed, for example, that 'hank', 'doorjamb' and 'peristyle' have been preferred over words like 'coil', 'doorpost' and 'colonnade'.

6.3.1 Translating 'diminutives'

A striking characteristic of the *Automata* and other Heronian works, in particular the *Pneumatica*, is the ubiquitous use of what are commonly, albeit sometimes erroneously, referred to as 'diminutives'. This broad category, which has been thoroughly studied by Petersen (1910) and others,²⁵⁹ includes, among others, the following kinds of terms: nouns equivalent to their primitives (for instance ἀγ-

²⁵⁹ See, most relevantly, Locker (1932; 1933) and Prêtre (1997a).

γείδιον) or whose diminutive force is faded (for instance παραστάδιον); instrumental nouns (for instance μοχλίων, κανόνιον); nouns conveying the idea 'made of' (for instance πινάκιον, σανίδιον); nouns whose diminutive meaning is closely associated or concomitant with the idea of resemblance (for instance σφαιρίον); nouns more or less exclusively denoting resemblance (for instance ἀστερίσκος). Unlike in previous translations, where it is not always clear why a diminutive form has been translated in such and such a way, words suffixed with -ιον, -ίς, -ίσκος, -(δ)άριον, -(ε)ίδιον, -ύλλιον have been studied individually. Their translation has been based upon (1) an investigation of the Heronian usage of such terms and their primitives wherever existing, (2) a careful perusal of previous scholarship (which, however, does not discuss all such terms) and (3) a comparison with terms unambiguously belonging to one of the above-mentioned classes. The results of this study showed, among other things, that, regardless of the class they belong to, a number of 'diminutives' tend to be used as stylistic variants in the treatise: ἀγγεῖον/ἀγγεῖδιον, ἄξων/ἄξόνιον, δελφίς/δελφινάριον/δελφινίσκος, ἐμπυελίς/ἐμπυελίδιον, κανών/κανόνιον, κεφαλή/κεφάλιον, κίων/κίόνιον/κιονίσκος, κύμβαλος/κυμβάλιον, λεπίς/λεπίδιον, μήρυμα/μηρυμάτιον, παραστάς/παραστάδιον, περόνη/περόνιον, πίναξ/πινάκιον, σανίς/σανίδιον, τρύπημα/τρυπημάτιον, τύμπανον/τυμπάνιον, χάλασμα/χαλασμάτιον/παραχαλασμάτιον, ὕσπληγξ/ὕσπληγγιον. A particularly noteworthy case is the term ζῶδιον, which, as has been convincingly shown by Kosmetatou (2004), can be used to denote both resemblance and small size (*contra*, Petersen 1910: 230). This term has been translated here as 'figurine', except where it is specified by the possessive pronoun αὐτῆς/αὐτοῦ (XX.2 [64.16-17], XXII.6 [74.2]).²⁶⁰ In cases where the precise value of a term cannot be easily determined (ἄρμένα, ἐπιούριον, πυργίον), the diminutive value is cautiously preferred.²⁶¹

²⁶⁰ Translating these two occurrences of the term as a diminutive would suggest that the figures of Athena and Ajax possess a figurine of some sort.

²⁶¹ While it is not possible here to discuss in detail Hero's use of (diminutive) suffixation, nor to assign suffixed words to individual categories, it is worth noting that, according to LSJ s.vv., the following terms are used as diminutives in the *Automata*: (1) ἄρμένα, (2) ἀστερίσκος, (3) δελφινάριον, (4) ἐπιούριον, (5) ἐμπυελίδιον, (6) ἰσχάριον, (7) κλειθρίον, (8) κυμβάλιον, (9) μηρυμάτιον, (10) πανθηρίσκος, (11) περόνιον and (12) τρόχιον. The entries for at least nos. (2), (3), (5), (6), (7), (8), (9), (10) and (11) should be corrected. Apart from τρόχιον and ζῶδιον, the terms that bear a diminutive sense in the treatise are ἄλυσείδιον, βαρύλλιον, θυρίς, κιβωτάριον, σπειρίον and σφαιρίον. Hellmann (1992: 378) cites the diminutive ὑποσπειρίδιον as occurring at III.1, but she is clearly mistaken. To the best of my knowledge, the term is nowhere attested.

6.3.2 Translating mathematical language, including the formula with ἔστω

Mathematical language also deserves some comment here. The following points are particularly relevant:

(1) Elliptical expressions referring to geometrical (or geometrised) entities have been generally left implicit as in the original Greek except when (a) it is necessary for the sake of clarity to specify what the objects in question are,²⁶² and/or when (b) such expressions are not otherwise understandable or translatable into English. In the latter two cases, in line with the editorial conventions followed in the translation (on which, see below), angle brackets are used to enclose elided expressions. As an example of (a), take, for instance, VII.1 [26.9], where we find the first mention of ἡ $\overline{\epsilon\alpha\zeta}$ [sc. γραμμή], ‘the <line> $\overline{\epsilon\alpha\zeta}$ ’ (later referred to more simply as $\overline{\epsilon\zeta}$, VII.2 [26.13]). For (b), see, most relevantly, XXIV.3 [82.12], where the hand and arm are described geometrically as τὸ πρὸς τῷ ὤμῳ (‘that <which originates> in the shoulder’). Also note that my use of angle brackets does not extend to expressions involving the term ἡ εὐθεῖα, because the reference to a line is unambiguous to modern readers.

(2) A related issue has to do with the way in which Hero refers to the diagrams accompanying his mechanical or geometrical descriptions. As shown by Roby (2016: 176-7), Hero – like Biton before him, and unlike Philo – establishes a direct relationship between the mechanical components and the corresponding elements in the diagrams, assigning letter labels to the objects described rather than resorting to the (typically Philonian) periphrastic use of ἐπί + genitive (on which, see point (4) below). As part of his direct approach, Hero describes geometrical/geometrised objects in mathematical style, using constructions such as ἔστω γάρ τι πλινθίον τὸ $\overline{\alpha\beta\gamma\delta}$ (V.3 [20.18-19]). In translating this and similar expressions, I have mostly opted for the more unconventional option and taken the verb εἰμί (or γίγνομαι) as existential (‘Let there be a case, $\overline{\alpha\beta\gamma\delta}$ ’, henceforth referred to as option (a)) rather than as copulative (‘Let $\overline{\alpha\beta\gamma\delta}$ be a case’ or ‘Let a case be $\overline{\alpha\beta\gamma\delta}$ ’, or, even worse, ‘Let **the** case be $\overline{\alpha\beta\gamma\delta}$ ’, henceforth referred to, respectively, as options (b¹), (b²) and

²⁶² Cf. the similar practice as regards points and lines in Netz’s translation of Archimedes’ *On the Sphere and the Cylinder* (Netz 2004b: 7).

(b³)).²⁶³ There are two main reasons for this choice. First, as pointed out by Netz (1999: 43-4) and most recently reiterated by Roby (2016: 175),²⁶⁴ the use of the article in expressions such as Euclid's ἔστω εὐθεῖα ἡ AB points to the conceptual pre-existence of AB *qua* straight line, and hence the more conventional understanding (option (b¹) is much more frequent than (b²) and (b³)) would yield 'let the straight line AB be a straight line' (where the straight line AB is assigned an attribute that it already possesses by virtue of its grammatical correlation with the indefinite noun εὐθεῖα). On the other hand, the first option (in this case, 'Let there be a straight line, AB') establishes (or, in fact, brings into existence) an object, only later assigning a diagrammatic location to it. Second, Federspiel (1995), who, like Netz (1999), advocates the use of existential εἶμι, persuasively demonstrates on linguistic and stylistic grounds that, except under specific circumstances, in a mathematical proposition the first occurrence of a geometrical object (as opposed to its second occurrence) is indefinite (this is what he calls 'Loi fondamentale', and is further articulated by his 'Règle I'),²⁶⁵ further noting that in such occurrences letter labels are used appositionally.²⁶⁶ This has two important implications. On the one hand, if letter labels are indeed used appositionally, then the more correct interpretation of the ἔστω formula is the one which takes the verb as existential (option (a)).²⁶⁷ In other words,

²⁶³ For exceptions, see below, n. 267. Baldi and Couture generally seem to take the verb as copulative (\approx option (b²)), although such expressions as 'Sia una cassetta a,b,c,d' (Baldi 20') and 'Sit... arcula αβγδ' (Couture 247) are inherently ambiguous. Schmidt opts for option (b¹), whereas Murphy vacillates between options (a) (with or without comma) and (b³).

²⁶⁴ Netz's discussion is erroneously cited by Roby (2016: 175 n. 83) as Netz (1999: 243).

²⁶⁵ The exceptions to this general rule are found in cases where the geometrical entities are determined either as representative of a class of elements ('Règle IIa') or in relation to their geometrical construction ('Règle IIb'). For an example of the former, see XXIV.2 [80.14], where ἡ χεὶρ ἡ αβ can be understood as a representative instantiation of the hands and arms of the Greek sailors. For an example of the latter, see VII.1 [26.11], where the expression ἐπεζεύχθωσαν αἱ δ̄ε, δ̄ζ stands for *ἐπεζεύχθωσαν αἱ δ̄ε, δ̄ζ εὐθεῖαι (or, simply, γραμμαῖ) rather than for *ἐπεζεύχθωσαν εὐθεῖαι αἱ δ̄ε, δ̄ζ (the points δ̄, ε̄ and ζ̄ have already been mentioned in the preceding context). On similar elliptical expressions, see below.

²⁶⁶ See also his earlier and less detailed discussion in Federspiel (1992: 15-17).

²⁶⁷ The main exceptions here are XVI.1 [54.13] and XVIII.1 [58.12]. In the former case, the object has been introduced in the immediately preceding context. In the latter case, stylistic and syntactic constraints prevent the verb from being translated as existential, and I very much doubt that it bears this sense in that specific context (οὐ [sc. τοῦ ἄξονος] τὸ πάχος ἔστω τὸ εζ). Federspiel's (1995: 267) interpretation of the relative pronoun in the comparable Apollonian phrase ἥ [sc. ἐπιφανείας] κορυφή τὸ Α σημείον (*Con.* 1.1 = 8.25 Heiberg) as a genitive of appurtenance depending on an understood (existential) ἔστω rather than as a complement of the noun κορυφή is unnecessarily convoluted.

translating the verb εἰμί as copulative confers (a certain degree of) definiteness where there is none in the original (Federspiel 1995: 249), and this is particularly obvious in the case of options (b¹) and (b³). On the other hand, apparently definite expressions such as ἐπεζεύχθω ἡ AB (where ἡ AB has not been mentioned in the preceding context) are in fact elliptical indefinite expressions in which letter labels are in apposition to an elided noun (in this particular case, *ἐπεζεύχθω εὐθεία ἡ AB).²⁶⁸ In all other cases, if the first mention of a geometrical entity is preceded by the article and is not determined either as representative of a class of elements or in relation to its geometrical construction ('Règles IIa-b', cf. above, n. 265), the use of the article is dictated by syntactic-stylistic reasons rather than by the actual definiteness of the object at hand ('Règle Ib', involving neutralisation of the opposition definite/indefinite). The most relevant cases that have been identified by Federspiel (1995: 255-7, 274-81) are those where (1) the noun agrees with an attributive participle which in turn governs a complement (for instance, Ἡ εἰς τὰς παραλλήλους εὐθείας εὐθεία ἐμπίπτουσα, Euc. 1.29) and (2) the noun is modified attributively by a prepositional phrase (for instance, Ἐὰν αἱ κατὰ κορυφὴν ἐπιφάνειαι, etc., Apollon. Perg. Con. 1.14 = 52.21 Heiberg). Generally speaking, therefore, my translation reflects the presence or absence of the definite article, but always omits it when it precedes the first mention of a geometrical/geometrised entity that occurs under the circumstances just mentioned. Consider the following examples:

- VII.1 [26.8] διήχθω τις ἡ $\overline{\alpha\delta}$ ('Let **a** certain <line>, $\overline{\alpha\delta}$, be drawn'). This is the first mention of line $\overline{\alpha\delta}$. The expression stands for *διήχθω τις εὐθεία ἡ $\overline{\alpha\delta}$, and its indefiniteness is emphasised by the use of the pronoun τις (on the usage, see Federspiel 1995: 272). So also VII.2 [26.14]. In this and similar cases, I do not specify that the line is straight to avoid excessive redundancy.

- XIII.3 [46.4-5] ἔστω δὲ καὶ ὁ ἐπικείμενος πυρὴν τῷ ναΐσκῳ ὁ $\overline{\kappa\lambda\mu}$ ('Let there be **a** knob placed on top of the shrine, $\overline{\kappa\lambda\mu}$ '). Unlike most of the components mentioned in the immediately preceding context, the knob has not been mentioned before. (Equally, the base of Dionysus has not been mentioned before, but the article preceding βάσις is justified by the genitive τοῦ Διονύσου.)

²⁶⁸ This is Federspiel's 'Règle Ic', and is amply demonstrated by the scholar in Federspiel (1995: 281-5).

The reference is therefore indefinite, and the article particularises the knob as lying on the roof (attributive participle governing a noun in the dative).

- XXVII.2 [98.12-13] ἡ δὲ ἐκκοπή ἡ ἐκ τῆς πλευρᾶς <ἔστω> ἡ $\overline{\alpha\beta}$ ('<Let there be> a notch on the side, $\overline{\alpha\beta}$ '). The notch has not been mentioned before, and hence the reference is indefinite. The article preceding ἐκκοπή is justified by the prepositional phrase ἡ ἐκ τῆς πλευρᾶς, which specifies the location of the notch. The same principle is at work at VI.4 [26.4-5], where, although the ring has already been mentioned before (VI.1 [24.3]), its mention (ὁ δὲ ἐν αὐτῇ κρίκος ὁ $\overline{\epsilon}$) is part of a reconfiguration in which all other components lack the article. Hero in this case could have dispensed with the article by adopting a different word-order (κρίκος δὲ ἐν αὐτῷ ὁ $\overline{\epsilon}$). Compare X.2 [34.6] ἐκκοπή δὲ ἐν αὐτῷ ἡ $\overline{\kappa\lambda\mu\nu}$.

(3) As a corollary to (2), note that, while letter labels usually stand in apposition to the first occurrence of a geometrical/geometrised entity, in subsequent occurrences they are found in attributive position. Contrast, for example, the first mention of the knob $\overline{\xi}$ at V.4 [22.4] with its second mention in the same paragraph (τὸν $\overline{\xi}$ τύλον, 22.10). The only way to distinguish between appositionally and attributively used letter labels is the use of punctuation. Therefore, following in the footsteps of Netz (2004b), I place appositionally used letter labels between commas (or between a comma and a semicolon or a period) whenever English syntax allows, even though such punctuation does not reflect that of the Greek text and may appear redundant at times.

(4) The periphrastic use of ἐπί + genitive to denote points of a diagram is found exclusively in the allegedly Philonian portions of BOOK TWO. Perhaps the most illustrative example is XXIII.8 [78.17] ἡ ἀρχὴ τῆς σπάρτου, ἐφ' ἧς ἐστὶ τὸ $\overline{\kappa}$ ('the end of the cord, where the <point> $\overline{\kappa}$ is'). In all other instances of this use, the verb 'to be' is understood, and has therefore been enclosed in angle brackets.

The editorial signs employed in the translation are the same as those used in the text and apparatus criticus (cf. *Conspectus siglorum et notarum*), except that square brackets enclose explanations or clarifications of terms.

6.4 Commentary

The Commentary is predominantly, but not at all exclusively, philological. Its purpose is threefold: (1) to explain as far as possible individual translation and textual choices; (2) to offer a fresh interpretation of the text that takes into account not only internal evidence but also how the work relates to the (literary, philosophical, technological) traditions within which it is situated; (3) to assess the technical feasibility of the mechanisms described in the text and, where possible, to provide evidence-based reconstructions. The decision to focus on Hero's language and style has been made in the belief that the close study of the text is the only way to understand it correctly. Commentary units correspond to the main textual units outlined in §5.1 above and are always prefaced by summarising synopses.

6.5 Illustrations

At the end of the thesis I append a number of illustrations (**Appendix 4**), namely (a) manuscript diagrams and (b) modern reconstructions.

As far as (a) is concerned, note that the vast majority of surviving manuscripts contain letter-labelled diagrams. These are usually interspersed in the text, but may also appear in the margins and, in one case, are appended at the end (**Bb**). Other manuscripts leave empty spaces (**Ac**, **Bc**, **La**, **M**, **Pd**, **Pe**, **Ph**, **Vd**), while yet others have both diagrams and empty spaces (**Ab**, **Lc**). One manuscript alone has neither diagrams nor empty spaces (**Ld**). As part of a tradition of mechanical diagrams (on which, see Roby 2016: esp. 154-163), our manuscript diagrams did not originate with Hero himself. Because they underwent a number of alterations in the course of their transmission over a long period of time, they cannot be taken in any way as a faithful reflection of the originals (see, for instance, my discussions in Comm. on XI.10 [40.18-19] and XVI.1 [54.13-14]). Therefore, when I refer to manuscript diagrams in my Commentary, I consider them, at best, as offering indicative rather than conclusive evidence. All manuscript diagrams included in this thesis were taken from the oldest manuscript, **A**, which is stored in the Biblioteca Nazionale Marciana in Venice, Italy. Permission to reproduce these diagrams has been

granted by the holding library. Unfortunately, because of budget limitations, it was not possible to provide coloured photographic reproductions. The reader should also bear in mind that, since the present study is mainly confined to a textual examination of Hero's treatise, I have not examined the Heronian diagrammatic tradition in any detail. All references to 'manuscript diagrams' in my Commentary should, nonetheless, be understood as implying that all the manuscript diagrams that I have seen are unanimous in their representation of specific elements.

As for (b), I provide modern reconstructions of the mobile automaton, which has been the primary focus of the project on Hero's automata as a whole. All such reconstructions are informed by a minimalist approach to design and are based on a careful study of the text itself. As such, they differ in a number of ways from the surviving manuscript diagrams, and are in no way intended to replace them. Unless otherwise stated, all modern illustrations are my own. The vast majority of my reconstructions were made using Vectr (<http://vectr.com>). **Figs. 2** and **6b** were made with SketchUp 2018. My own reconstructions, of course, make no pretence to absolute accuracy.

Given the mutually supporting relationship between text and images, the reader may wonder why no attempt has been made to intersperse illustrations throughout the text. The choice to relegate illustrations to an appendix was made to allow strict synchronisation between text and translation. All references to illustrations conveniently appear in the right margin of the English translation next to the pertinent portion of the text.

CONSPECTVS SIGLORVM ET NOTARVM

Codices potiores

A	codex Marcianus gr. Z. 516, saec. XIII
G	codex Guelferbitanus Gudianus gr. 19, saec. XVI
M	codex Magliabechianus II.III.36, saec. XVI
T	codex Taurinensis B.V.20, saec. XVI (1541)
a	consensus codicum AGMT

Rarius citantur

Aa	codex Ambrosianus C 266 inf., saec. XVI
Ab	codex Ambrosianus D 131 inf., saec. XVI
Ac	codex Amstelodamensis III.F.26 (olim 104), saec. XVII
Ad	codex Angelicanus gr. 109 (olim S.I.17), saec. XVI (1548–1553)
(Ae)	codex deperditus Argentoratensis C.III.6, saec. XVI
Bb	codex Barberinianus gr. 261 (olim II.82), saec. XVI-XVII
Bc	codex Baroccianus gr. 169, saec. XV (1476–1500)
Ea	codex Escorialensis T.I.3, saec. XVI
F	codex Fabritius 93 kvart (olim Hauniensis universalis 93), saec. XVIII
La	codex Leidensis Bonaventurae Vulcanii 4, saec. XVI/XVII (1500–1600?)
Lb	codex Leidensis Scaligeri 45, saec. XV ex./XVI ¹
Lc	codex Leidensis Vossianus Miscellanaeus 6, saec. XVII
Ld	codex Leidensis Vossianus Miscellanaeus 17, saec. XVII
Mb	codex Matritensis 4788 saec. XVI
Mc	codex Monacensis gr. 431, saec. XVI
O	codex Oxoniensis Collegii Beatae Mariae Magdalenae 12, saec. XVI (1569–1570)
Pa	codex Parisinus gr. 2428, saec. XVI
Pb	codex Parisinus gr. 2430, saec. XVI/XVII (1590–1610)
Pc	codex Parisinus gr. 2431, saec. XVI (1540–1550)
Pd	codex Parisinus gr. 2432, saec. XVI (1555–1575)

Pe	codex Parisinus gr. 2434, saec. XVI (1520–1570)
Pf	codex Parisinus gr. 2519, saec. XV vel XVI
Pg	codex Parisinus gr. 2520, saec. XVI
Ph	codex Parisinus suppl. gr. 11, saec. XVI
R	codex Riccardianus gr. 47, saec. XVI
Ta	codex Taurinensis B.I.18, saec. XVI
Tb	codex Thottianus 215, saec. XVI
Vd	codex Vindobonensis suppl. gr. 21, saec. XVII (c.1600)

Viri docti

Baldi	Bernardino Baldi
Brinkmann	August Brinkmann
Diels	Hermann Diels
Egger	Maximilien Egger, sed in uno tantum loco incertum est utrum agatur de Maximilien Egger an Émile Egger; vide supra, p. xviii
Haase	Friedrich Haase
Hildebrandt	Paul Hildebrandt
Olivieri	Alessandro Olivieri
Prou	Victor Prou
H. Schöne	Hermann Schöne
R. Schöne	Richard Schöne
Schmidt	Wilhelm Schmidt
Susemihl	Franz Susemihl
Weil	Henri Weil

Alia breviata

X ¹	lectio primae manus	adn. crit.	adnotationes criticae
X ²	correctio vel lectio secundae manus	app. crit.	apparatus criticus
X ^{ac}	lectio ante correctionem	cens.	censuit
X ^{pc}	lectio post correctionem	cett.	ceteri (editores)
X ^{cp}	lectio in compendio	con.	coniecit
X ^{mg}	lectio in margine scripta	corr.	correxit
X ^{sl}	lectio supra lineam scripta	del.	delevit
††	corruptela	distinx.	distinxit
<αβγ>	litterae ab editore additae	dub.	dubitanter
{αβγ}	litterae ab editore deletae	edd.	editores
<***>	lacuna suppleta est	fort.	fortasse
[***]	litterae deperditae	interpunx.	interpunxit (-erunt)
add.	addidit	l(l).	linea (-ae)
		n.	nota
		obl.	oblocutus est
		om.	omisit (-erunt)
		p(p).	pagina (-ae)
		prob.	probante (-ibus)
		rec.	recepit (-erunt)
		suppl.	supplevit
		transp.	transposuit

TEXT AND TRANSLATION

ΗΡΩΝΟΣ ΑΛΕΞΑΝΔΡΕΩΣ ΠΕΡΙ ΑΥΤΟΜΑΤΩΝ

- I (1) Τῆς αὐτοματοποιητικῆς πραγματείας ὑπὸ τῶν προτέρων ἀποδοχῆς ἡξιωμένης διὰ τε τὸ ποικίλον τῆς ἐν αὐτῇ δημιουργίας καὶ διὰ τὸ ἔκπληκτον τῆς θεωρίας <***>. 5
ἔστι γάρ, ὥς συνελόντι εἰπεῖν, πᾶν μέρος τῆς μηχανικῆς ἐν αὐτῇ τῇ αὐτοματοποιητικῇ παραλαμβανόμενον διὰ τῶν κατὰ μέρος ἐν αὐτῇ ἐπιτελουμένων.
- (2) ἔστι δὲ αὐτῆς ἡ ἐπαγγελία τοιάδε· κατασκευάζονται 10
ναοὶ ἢ βωμοὶ σύμμετροι αὐτόματοί τε προάγοντες καὶ κατὰ τινὰς ὠρισμένους ἰστάμενοι τόπους, καὶ τῶν ἐνόντων αὐτοῖς ζφδίων ἕκαστον ἰδίᾳ κινεῖται πρὸς λόγον τὸν κατὰ τὴν προκειμένην πρόθεσιν ἢ μῦθον ἀρμόζοντα, καὶ εἰς τὸν ἐξ ἀρχῆς ἀποκαθίστανται τόπον. τὰ μὲν οὖν τοιαῦτα δημιουργήματα τῶν αὐτομάτων καλεῖται ὑπάγοντα. 15
- (3) ἔστι δὲ καὶ ἕτερον εἶδος ἐν αὐτοῖς, ὃ καλεῖται στατόν. ἔστι δὲ καὶ τούτου ἡ ὑπόσχεσις τοιαύτη· ἐπὶ τινος κιονίσκου πίναξ ἐφέστηκε θύρας ἔχων ἀνοιγομένας, καὶ ἐν αὐτῷ <φαίνεται> διάθεσις ζφδίων πρὸς τινὰ μῦθον διεσκευασμένων. 20

2 περὶ αὐτομάτων scripsi : περὶ αὐτοματοποιητικῆς AG : περὶ αὐτοματοποιητικῶν MT : περὶ αὐτοματοποιῶν Wescher : αὐτοματοποιῶν Prou : περὶ αὐτοματοποιήτων Dindorf; de titulis vide Introductionem, pp. lxxiv-lxxi
3 αὐτοματοποιητικῆς a : αὐτοματοποιῆς Dindorf 3-4 προτέρων GM : πρότερον AT 5 lacunam statui secutus Schmidt, qui verba ex *Spir.* 2.7-10 ἀναγκαῖον... εἰσθέσθαι dub. suppl. in app. crit., obl. Olivieri 6 συνελόντι εἰπεῖν ὡς a : transp. Diels ἐν AMT : καὶ ἐν G 9 ἔστι δὲ A^{ac} : ἔστιν A^{pc} G MT 10 ἢ a : καὶ Schmidt dub. in app. crit. προάγοντες Brinkmann : προσάγονται a : προσαγόμενοι Diels 14 post τόπον lacunam dub. statuit Schmidt in app. crit. 17 ἢ om. M 19 <φαίνεται> Schmidt dub. in app. crit. : <γέγραπται> Brinkmann : <***> Schmidt in textu 19-20 διεσκευασμένων M T^{pcsl} : διεσκευασμένων A T^{ac} : διεσκευασμένα G

HERO OF ALEXANDRIA'S *ON AUTOMATA*

- I **(1)** Since the subject of automata-making was favourably received by the former generations on account of both the varied types of craftsmanship in it and the astounding character of the spectacle <***>. For, to speak briefly, every part of mechanics is taken over in the very practice of automata-making, through the things which are completed in it one by one.
- (2)** Its scope is as follows: shrines or altars of suitable size are constructed, which move forward by themselves and stop at certain defined locations; and each of the figurines that are inside them moves by itself in accordance either with the set purpose or with the appropriate story, and <eventually> they return to their starting point. Therefore, such crafted types of automata are called 'mobile'.
- (3)** However, there is also among them [the automata] another kind, which is called 'stationary'. Its purpose is as follows: a box with open doors stands on a pillar, and inside it <appears> an arrangement of figurines prepared for the sake of some story.

- (4) κεκλεισμένου οὖν τοῦ πίνακος αἱ θύραι αὐτόματοι ἀνοίγονται, καὶ φαίνεται ἡ τῶν ζωδίων τάξις γεγραμμένη· καὶ μετ' οὐ πολλὸν χρόνον κλεισθεισῶν τῶν θυρῶν καὶ ἀνοιχθεισῶν πάλιν αὐτομάτως, ἑτέρα φαίνεται διάθεσις ζωδίων ἀρμόζουσα τῇ πρότερον φανείσῃ· καὶ πάλιν κλει- 5 σθεισῶν καὶ ἀνοιχθεισῶν τῶν θυρῶν ἑτέρα διάθεσις πάλιν φαίνεται ζωδίων ἀρμόζουσα τῇ πρότερον κειμένη, καὶ ἥτοι <αὕτη> ἀπαρτίζει τὸν προκείμενον μῦθον ἢ πάλιν μετὰ ταύτην ἑτέρα φαίνεται, ἄχρις ἂν ἀπαρτισθῇ ὁ μῦθος.
- (5) καὶ τῶν φαινομένων δὲ ζωδίων τῶν γεγραμμένων ἐν 10 τῷ πίνακι ἕκαστον ἐν κινήσει δύναται φαίνεσθαι, ἐὰν ἀπαιτῇ ὁ μῦθος, οἷον ἂ μὲν πρίζοντα, ἂ δὲ σκεπαρνίζοντα, ἂ δὲ σφύραις ἢ πελέκεσιν ἐργαζόμενα, ψόφον ποιοῦντα καθ' ἑκάστην πληγὴν καθάπερ ἐπὶ τῆς ἀληθείας.
- (6) δύνανται δὲ καὶ ἕτεραι κινήσεις ὑπὸ τὸν πίνακα γίγνε- 15 σθαι, οἷον πῦρ ἀνάπτεσθαι ἢ ζῳδία ἐπιφαίνεσθαι πρότερον μὴ φαινόμενα καὶ πάλιν ἀφανίζεσθαι. καὶ ἀπλῶς, ὥς ἂν τις ἔλῃται δυνατόν ἐστι κινεῖν μηδενὸς προσιόντος τοῖς ζωδί- οῖς.
- (7) ἔστι δὲ ἡ τῶν στατῶν αὐτομάτων ἐνέργεια ἀσφαλε- 20 στέρα τε καὶ ἀκινδυνότερα καὶ μᾶλλον πᾶσαν ἐπιδεχομένη διάθεσιν τῶν ὑπαγόντων. ἐκάλουν δὲ οἱ παλαιοὶ τοὺς τὰ

1 κεκλεισμένου AG : κεκλεισμένων T : κεκλεισμένοι M οὖν <ἐξ ἀρχῆς> H. Schöne 4 πάλιν αὐτομάτως huc transposui : post τῶν θυρῶν (3) a 8 <αὕτη> Schmidt dub. in app. crit. ἀπαρτίζει R. Schöne : ἀπαρτίζουσα a 10 δὲ om. MT 11 πίνακι A^{pc} (va altero addito in mg.) G : πίκακι A^{ac} : πίνακι va T : πίνακι ἴνα M : πίνακι ἐν R. Schöne, rec. Schmidt 12 ἀπαιτῇ AG : ἀπαιτεῖ M : εὐπαιτῇ T πρίζοντα AG : περιζοντα T : θερίζοντα M σκεπαρνίζοντα M^{2mg} : σκεπαρνίζοντα M¹ T : σκεπαρνίζοντα AG 13 σφύραις AM T : ἀφύραις G^{cp} ἐργαζόμενα , <ἂ δὲ ἀρίσι καὶ τρυπάνοις χρώμενα> dub. Schmidt in app. crit. ποιοῦντα AG T : ποιοῦνται M 15 ὑπὸ a La^(in textu) : ὑπὲρ La^{mg} : κατὰ Diels 18 ἔλῃται a : προήλεται H. Schöne προσιόντος A G^{ac} MT : προσιέντος G^{pc} 21 ἀκινδυνότερα M : ἀκινδυνωτέρα AG T

(4) So, when the box is closed, the doors open by themselves, and the painted array of figurines appears; not long after, once the doors have closed and opened again automatically, another arrangement of figurines, corresponding with the one appeared before, appears; once the doors have closed and opened again, another arrangement of figurines, corresponding with the one set up before, appears again, and either <this> completes the pre-conceived story or yet another arrangement appears after this one, until the story is brought to an end.

(5) And then each of the painted figurines displayed in the box can be seen in motion, if the story requires it: for example, some sawing, some hewing with the adze, some others working with hammers or axes, so as to make noise with each blow, just like in real life.

(6) Other movements can also be performed inside the box, such as the lighting of a fire or the appearance of figurines which were not visible before, and their disappearance. In short, anyone can set the figurines in motion as they may choose with no one going closer to them.

(7) Then, the mechanism of the stationary automata is safer and freer from danger, as well as admitting of more types of arrangements than the mobile ones. Former generations used to call those crafting such automata 'won-

τοιαῦτα δημιουργοῦντας θαυματουργοὺς διὰ τὸ ἔκπληκτον
τῆς θεωρίας.

(8) ἐν μὲν οὖν τούτῳ τῷ βιβλίῳ περὶ τῶν ὑπαγόντων γρά-
φομεν ἐκθέμενοι διάθεσιν ποικίλην κατὰ γε ἡμᾶς, ἥτις
ἀρμόσει πάσῃ διαθέσει πρὸς τὸ δύνασθαι τὸν προαιρούμε- 5
νον ἑτέρως διατίθεσθαι μηδὲν ἐπιζητοῦντα πρὸς τὴν τῆς
διαθέσεως ἐνέργειαν· ἐν δὲ τῷ ἐξῆς περὶ τῶν στατῶν αὐτο-
μάτων γράφομεν.

II **(1)** Δεῖ δὲ πρῶτον ἀπόκροτον εἶναι καὶ ἀκλινὲς καὶ ὁμαλὸν
τὸ ἔδαφος ἐν ᾧ μέλλει τὸ αὐτόματον ὑπάγειν, ἵνα μήτε οἱ 10
τροχοὶ αὐτοῦ καταδύνωσι πιεζόμενοι μήτε ἐμποδίζονται
ὑπὸ τραχύτητός τινος μήτε πρὸς ἀνάβασιν βιαζόμενοι εἰς
τὸ ὀπίσω ἐπινεύωσιν.

(2) εἰ δὲ μὴ ὑπάρχη τὸ ἔδαφος τοιοῦτον οἷον εἴρηται, δεῖ
σανίδας ἀπορθώσαντας ἐπὶ τοῦ ἐδάφους διατιθέναι, ἐν αἷς 15
κατὰ μῆκος ἔσονται σωλῆνες δι' ἐφηλωτῶν κανόνων πρὸς
τὸ τοὺς τροχοὺς ἐν τοῖς σωλῆσι κυλίεσθαι. δεῖ δὲ τὰ ὑπά-
γοντα κατασκευάζειν ἐκ κούφων τε καὶ ξηρῶν ξύλων, κἂν
ἐξ ἄλλης δέ τινος ὕλης ὑπάρχη τι ἐν αὐτοῖς κατεσκευασμέ-

3 τούτῳ A G M : τούτων T 4 ἐκθέμενοι a : ἐκτιθέμενοι H. Schöne κατὰ
γε AG : κατάγε M : κάταγη T^{ac} : κατάγη T^{pc} 5 διαθέσει a : προθέσει
Brinkmann 6 ἑτέρως A G T : ἕτερον M μηδὲν ἐπιζητοῦντα M : μὴ ἐνεπι-
ζητοῦντα A G T 8 γράφομεν Schmidt dub. in app. crit. : γράφομεν a
11 ἐμποδίζονται A : ἐμποδίζονται G T : ἐκποδίζονται M 15 ἀπορθώσαντας
Schmidt : ἀποθώσαντας A G : ἀποθώσαντες M¹ T : ὑποθήσαντας M^{2mg} :
<ἀκλινεῖς> ἀπορθώσαντας Schmidt dub. in app. crit. : ἀπωθήσαντας Prou
ἐν a : ἐφ' Prou 16 δι' ἐφηλωτῶν A G : δι' ἐφηλατῶν T : διεφήλη τῶν M :
διεφηλετῶν vel διεφηλητῶν codex a Baldi adhibitus : διεφηλοτῶν (sic) Baldi
18 τε om. M 19 ὑπάρχη τι G : ὑπάρχειν τι A^(ev cp) : ὑπάρχων τι T : ὑπάρ-
χοντι M 19-8.1 κατεσκευασμένον Ea Lb : κατασκευασμένον a

der-workers' because of the astounding character of the spectacle.

(8) Therefore, in this book I am writing on mobile automata, setting forth a complex configuration of my own which will adapt to every <other> arrangement; in this way, whoever chooses to arrange differently will be able <to do so>, not lacking anything for the actualisation of the arrangement. In the following <book> I will write on stationary automata.

II (1) First of all, the ground on which the automaton is to move must be hard, horizontal and level, in order for its wheels neither to sink when they are pressed down, nor to be hindered by any unevenness, nor to tilt backwards down while forcing their way up.

(2) But if the surface is not such as has been described, boards must be laid level on the ground, on which there will be grooves lengthwise with rods nailed on them in order for the wheels to roll along the grooves. Mobile automata must be constructed from light and dry timber, and should any other component of theirs be constructed from some other material, it will be necessary to try to make this too as light as possible in order that the auto-

νον, καὶ τοῦτο δεήσει ὥς κουφότατον πειρᾶσθαι ποιεῖν,
ἵνα μὴ διὰ τὸ βάρος δυσκίνητα γένηται.

(3) δεῖ δὲ καὶ ὅσα ἐγκυκλίους στροφὰς ἢ κινήσεις ποιεῖται,
ταῦτα ἔντορνά τε ἀκριβῶς καὶ περὶ ᾧ κινεῖται λεία καὶ μὴ
τραχέα ὑπάρχειν, οἷον οἱ μὲν τροχοὶ περὶ κνώδακας σιδη- 5
ροῦς ἐμβεβηκότας εἰς ἐμπυελίδας σιδηρᾶς, τὰ δὲ ζώδια
περὶ ἄξονας χαλκοῦς ἐμβεβηκότας εἰς χοινικίδας χαλκᾶς
συνεσμηρισμένας αὐτοῖς.

(4) καὶ ἔλαιον δὲ παρεπιχέειν δεήσει εἰς ταῦτα, ὅπως κατὰ
πάντα τρόπον εὐκύλιστα πάντα ὑπάρχει καὶ μηδὲν παρὰ 10
τοῦτο σφίγμα γένηται· εἰ δὲ μή, οὐκ ἔσται τῶν προκειμέ-
νων κατὰ λόγον οὐδὲ ἓν. δεῖ δὲ καὶ τὰς σπάρτους, αἷς εἰς
ταῦτα προσχρώμεθα, μήτε ἐπέκτασιν μήτε συστολὴν λαμ-
βάνειν, ἀλλὰ τοιαύτας διαμένειν τοῖς μήκεσιν οἷαι καὶ ἐξ
ἀρχῆς κατεστάθησαν. 15

(5) τοῦτο δὲ ἔσται, ἐὰν βαλόντες αὐτὰς περί τινας πασσα-
λίσκους, διατείναντες εὖ μάλα καὶ ἐάσαντες αὐτὰς ὀλίγον
χρόνον πάλιν ἐπεκτείνωμεν καὶ τοῦτο πλεονάκις ποιήσαν-
τες κηρὸν μετὰ ῥητίνης καταψήσωμεν. βέλτιον δ' εἰ καὶ
βάρος ἐξ αὐτῶν ἐξάψαντες ἐάσομεν ἐπὶ πλείονα χρόνον. 20
προβασανισθεῖσα δὲ οὕτως οὐδεμίαν ἐπέκτασιν λήψεται ἢ

1 καὶ Haase : εἰ **a** 3 ὅσα **a** : ὅς' ἂν Schmidt ἐγκυκλίους M : ἐνὶ κλοιούς
A : ἐν ἡν κλοιούς T : ἐν ἡν κλοιουσῶν G (ἐνὶν addito in mg., ut videtur) ποιεῖται
Brinkmann : ποιεῖσθαι **a** : ποιῆται Schmidt 6 εἰς om. T¹ : add. T^{2mg} ἐμπυ-
ελίδας A G M^{ac} : πυελίδας M^{pc} : ἐμπυελύσθας T 7-8 χαλκᾶς vac. c.5 συνε-
σμηρισμένας MT 8 συνεσμηρισμένας A^{pc} G M T : ἔχων εσμηρισμένας
A^{ac} (ων cp) αὐτοῖς A^{pc} M T : αὐτὰς A^{ac} G 9 παρεπιχέειν A T : περὶ ἐπιχέειν
G : ἐπιχέειν M^{pcsl} : παρπιχέειν M^{ac} 10 πάντα¹ A^{cp} G M T, del. R. Schöne,
prob. Schmidt τρόπον **a** : τόπον Brinkmann πάντα² A^{cp} G : πάντη M :
πάντι T ὑπάρχει A G : ὑπάρχειν M T 11 οὐκ om. M 12 οὐδὲ ἓν (Ae) Pc
Vd : οὐδέεν A G : οὐδέεν M T 13 συστολὴν A^{pc} M : σωλὴν A^{ac} G T 16 βα-
λόντες H. Schöne : λαβόντες **a** : περιβαλόντες Schmidt dub. in app. crit.
17 <καὶ> διατείναντες Diels 19 κατεψήσωμεν **a** : corr. Schmidt δ' εἰ A G
: δὲ εἰ M T 20 βάρος M : βάρους A G T ἐάσομεν A^{pc} G : ἐάσωμεν A^{ac} M
T πλείονα A G : πλείον M T

mata may not become difficult to move because of their own weight.

(3) Furthermore, anything that makes circular rotations or movements must be accurately turned and anything around which <things> are moved must be smooth and not rough, for example, the wheels around iron pivots inserted into iron sockets, and the figurines around bronze axles fitted tightly into bronze collars.

Fig. 3 (cf. II.7)

(4) It will also be necessary to pour oil onto these tools so that they may all be easy to rotate in every possible way and there may be no jamming at all. Otherwise, nothing of what has been previously said will go according to plan. Also, the cords which we use for these purposes must neither stretch nor contract, but remain the length they were at the very beginning.

(5) This will be accomplished if we put them around some pegs, carefully stretch them to the utmost, leave them <in place> for a short time and stretch them again; and <this will be accomplished if,> after repeating the entire process several times, we smear a compound of wax and resin. It will also be better for us to hang a weight on them and leave them for a rather long time. If it [the cord] is pre-

παντελῶς βραχεῖαν. ἢ πάλιν ἀποκόψομεν, ὅταν ἐξαρτύσαντες τὸ αὐτόματόν τινα αὐτῶν παρεκτεταμένην εὗρωμεν.

(6) νευρίνω δὲ οὐδενὶ δεῖ χρήσθαι, ἐπειδὴ παρεκτείνεται ἢ
 συστέλλεται κατὰ τὴν τοῦ ἀέρος περίστασιν, εἰ μὴ ἄρα 5
 ὅταν δέη ὑσπληγγί χρήσασθαι. ὁ δὲ ὑσπληγξ ἔστω καθά-
 περ ἐν τοῖς καταπέλταις ὁ ἄξων κατατεταγμένος ἐν τῷ
 ἡμιτονίῳ, ὡς ἐξῆς ἔσται δῆλον. πάντα δὲ ταῦτα τὰ ὑπά-
 γοντα τὴν ἀρχὴν λαμβάνει τῆς κινήσεως διὰ ὑσπληγγος ἢ
 λείας μολιβῆς. 10

(7) κοινὸν δὲ ἐστὶ τοῦ κινουντος καὶ τοῦ κινουμένου
 σπάρτος ἔχουσα τὴν μὲν μίαν ἀρχὴν πρὸς τῷ κινουντι
 προσδεδεμένην, τὴν δὲ ἐτέραν πρὸς τῷ κινουμένῳ προσ-
 ηγκυλωμένην. τὸ δὲ κινούμενον ἄξων ἐστί, περὶ ὃν ἡ
 σπάρτος περιεΐληται. τῷ δὲ ἄξονι προσαραρότες εἰσὶ τρο- 15
 χοί, ὥστε τοῦ ἄξονος στρεφομένου καὶ ἀπειλισσομένης
 τῆς σπάρτου συστρέφεσθαι καὶ τοὺς τροχοὺς ἐρείδοντας
 ἐπὶ τὸ ἔδαφος. τοῖς δὲ τροχοῖς περικέεται τὸ τοῦ ὑπάγοντος
 αὐτομάτου πλινθίον.

1 ἢ A^{ac} G M T : καὶ A^{pccp} (ut videtur) 1-2 ἐξαρτήσαντες a : corr. Brinkmann et
 H. Schöne 2 παρεκτεταμένην Schmidt : παρεντεταμένην G : παρεντεταμέ-
 νην A^{pc} : παρενταταμένην A^{ac} : παρεντεταμένον M : παρεντεταμένον T
 4 οὐδενὶ δεῖ G^{pc} (ut videtur) : οὐδενὶ δεῖ A : οὐδενὸς ἰδεῖ G^{ac} T : οὐδενὸς δεῖ M
 ἐπειδὴ παρεκτείνεται A^{pc} G T : ἐπειδὴ παρεκτείνεται A^{ac} : ἐπειδὴ περ ἐκτείνε-
 ται M ἢ Schmidt dub. in app. crit. : καὶ a 7 καταπέλταις A G : κατὰ
 πέλταις M^{pchl} T : πέλταις M^{ac} ἄξων a Pe : ἄγκων (sic) Pe^{sl} κατατεταγμένος
 A G T : κατατεταμένος M : ἐντεταμένος Ab Ac Bb La Lc Ld 8 ἔσται δῆλον
 M : ἔσ (vel ἐσ vel εσ) vac. c.3 λον A (ἐσ altero addito in mg.) G T ταῦτα A (ante ταῦτα
 duabus litteris erasis) G : καὶ ταῦτα M : καταῦτα T 11 κοινὸν A^{pc} G : κοινὸς A^{ac} M
 T καὶ A G M T^{2mg} : τῆς T¹ κινουμένου A M T : κοινουμένου G 12 μὲν
 om. M 13-14 προσηγκυλωμένην Brinkmann : προσηλωμένην a 15 περι-
 εΐληται M : περιεΐληται A : περιεΐληται G T 16 ἀπειλισσομένης A G M^{ac}
 T : ἐπειλισσομένης M^{pchl} 17 ἐρείδοντας La Ph : ἐρείδοντος a 18 ἐπὶ A G :
 κατὰ M : om. T an τοῦ ἔδαφους? 19 αὐτομάτου F : αὐτομάτως M :
 αὐτομάτος A G T : αὐτόματος Ea Ta

tested in this way, it will stretch not at all or really very little. Or again, if we find, after getting the automaton strung, that one of those <cords> is stretched, we will cut it off.

(6) Nothing made of sinew must be used – except when it is necessary to make use of a *hysplēnx* – as it [the sinew] stretches or contracts depending on atmospheric conditions. Let the *hysplēnx* be just like the axle which in catapults is set in the half-spring, as will become apparent in what follows. All these mobile automata start moving by means of a *hysplēnx* or a lead counterweight.

(7) What causes motion and what is moved have a cord in common, which has one end bound to what causes motion, and the other looped around what is moved. What is moved is an axle around which the cord is wound. Wheels are fitted to the axle so that, when the axle rotates and the cord unwinds, the wheels, resting on the ground, may rotate as well. The case of the mobile automaton encircles the wheels.

(8) τάσιν δὲ ὑσπληγγος ἢ βάρος λείας δεῖ πρὸς τὰ ὅλα ἡρμόσθαι, ὅπως μὴ κατακρατῆται ἥτοι τὸ βάρος ἢ ἡ τοῦ ὑσπληγγος τάσις ὑπὸ τοῦ πλινθίου. αἱ δὲ ἐκτὸς τῆς πορείας κινήσεις γίνονται πασῶν τῶν σπάρτων προσηγκυλωμένων μὲν τοῖς κινουμένοις ὀργάνοις, ἀποδεδεμένων δὲ εἰς τὴν λείαν. ἡ δὲ λεία ἐστὶν ἓν τινι σύριγγι, ἀρμοστῶς καὶ εὐλύτως δυναμένη καταβαίνειν εἰς αὐτήν.

(9) ἐν δὲ τῇ σύριγγι ἐπὶ μὲν τῶν ὑπαγόντων ἢ κέγχρος ἢ νᾶπυ ἐμβάλλεται διὰ τὸ κοῦφά τε ἀμφοτέρω εἶναι καὶ ὀλισθηρά, ἐν δὲ τοῖς στατοῖς ἄμμος ξηρὰ ἐμβάλλεται, ὧν ἐκρεόντων διὰ τοῦ πυθμένος τῆς σύριγγος ἢ λεία ἡρέμα καταφερομένη τὰς κινήσεις ἀποτελεῖ ἐπισπωμένη ἐκάστην σπάρτον. ἀρχὴ δὲ κινήσεως ἐστὶ τάσις σπάρτου, κινήσεως δὲ τέλος ἀπόλυσις σπάρτου ἐκπεσούσης τῆς ἀγκύλης ἀπὸ τοῦ τύλου τοῦ ἐν τῷ κινουμένῳ ὀργάνῳ.

(10) αἱ δὲ ὑπὸ τῆς λείας ἐλκόμεναι σπάρτοι πᾶσαι ἰσοταχῶς μὲν ἔλκονται, οὐκ ἰσοταχεῖς δὲ τὰς κινήσεις ποιοῦνται διὰ τὸ μὴ περὶ ὅμοια ὄργανα αὐτὰς περιειλεῖσθαι, ἀλλὰ ἅς μὲν περὶ μείζονας κύκλους, ἅς δὲ περὶ ἐλάσσονας. δεῖ δὲ

1 βάρος **a** : corr. Haase 2 κατακρατῆται **A G** : κατακρατεῖται **M T** an τὸ <τῆς λείας> βάρος? ἢ om. **M** 3 ἐκτὸς Schmidt dub. in app. crit. : ἐκ **a** 5 ἀποδεδεμένων **a** : an ἀποδεδεμένων? 6 ἀρμοστῶς **A^{ac} G** : ἀρμοστοι vel ἀρμοστοῖς **A^{pcsl}** : ἀρμοστῇ ὡς **T** : ἀρμοστή ὡς **M** 8 τῇ **A^{pc}** : τῷ **A^{ac} G M T** κέγχρος **M** : κέχρος **A G T** 9-10 διὰ...ἐμβάλλεται add. **A^{mg}** 9-10 ὀλισθηρά **La** : ὀλιστηρά **a** 10 στρατοῖς **T** 11 διὰ om. **M** (*spatio vacuo relicto*) τῆς **A G** : καὶ **M T** 12 ἀποτελεῖ **a** : an ἐπιτελεῖ? 13 τάσις ed. princ. : πάσης **A G T** : σπάσις **M** 14 τέλος scripsi : στάσις **a**, hoc verbum ex glossemate ortum existimo : στάσις **Pf** : τάσις **La** 16 σπάρτοι **A^{pc} G M** : σπάρται **A^{ac} T** 17 οὐκ ἰσοταχεῖς **A G T** : ἀνισοταχεῖς **M^{pcsl}** : ἀκισοταχεῖς **M^{ac}** ποιοῦνται **A^{pc} G T¹** : ἐμποιοῦνται **A^{ac} M T²** 18 μὴ om. **T¹** : add. **T^{2mg}** αὐτὰς **A G T^{ac}** : αὐτοῖς **M T^{pc}** 19 μείζονας **M** : μείζονα **A G T**

(8) The tension of the *hysplēnx* or the heaviness of the counterweight must be adjusted to the whole, so that neither the heaviness nor the tension of the *hysplēnx* may be overcome by the case. Movements other than the journey [of the case] occur with all the cords, on the one hand, looped around the instruments being moved and, on the other, bound to the counterweight. The counterweight is inside a tube, in which it can also descend fittingly and easily.

(9) In the case of mobile automata, either millet or mustard is put inside the tube, since both of them are light and flow easily, whereas in stationary automata dry sand is put inside; and when these <grains> pour out through the bottom of the tube, the counterweight descends gently and brings about motions by drawing each cord. The origin of motion lies in the tension of a cord, while the end of motion <lies in> the loosening of a cord, that is, when the loop falls off the knob on the instrument being moved.

(10) Despite the fact that the cords being drawn by the counterweight are all drawn at equal speeds, they do not generate motions with equal speeds because they are not wound around equal instruments, but some are wound around bigger circles, some around smaller ones. Cords

τῶν μὴ ἅμα κινουμένων ὀργάνων τὰς σπάρτους μὴ ἅμα τετάσθαι, ἀλλὰ τῶν ὕστερον κινουμένων τὰς σπάρτους χαλάσματα ἔχειν.

(11) τὰ δὲ χαλάσματα μηρύματα δεῖ ποιεῖν καὶ προσκολλᾶν κηρῷ ἐντὸς τοῦ πλινθίου κατὰ τὸν ἐπιβάλλοντα τόπον, ὅπως ἡ λεία ἐπισπωμένη τὸ χάλασμα πραέως τείνη τὴν σπάρτον. προσέχειν δὲ δεῖ καὶ ταῖς σπάρτοις, ὅπως ἐκάστη αὐτῶν τῷ ἰδίῳ ὀργάνῳ προσαγκυλωθῇ καὶ μὴ ἐπ' ἀριστερὰ τὴν ἐπέιλησιν λάβῃ· μιᾶς γὰρ αὐτῶν ἀλλαγείσης ἢ ἐπ' ἀριστερὰ ἐπειληθείσης τὰ ὅλα στάσιν λήψεται.

(12) δεῖ δὲ καὶ τὰς τῶν ἀρχαίων ἐκφυγεῖν διαθέσεις, ὅπως καινότερον τὸ κατασκευάσμα φαίνεται· δυνατόν γάρ, ὡς προεῖρηται, ταῖς αὐταῖς μεθόδοις χρώμενον ἑτέρας καὶ ἑτέρας διαθέσεις ποιεῖσθαι. βέλτιον δ' ἐν τούτοις ἀναστρέφεται ὁ χαριεστέραν ἐπινοῶν διάθεσιν. ἦν δὲ ἡμεῖς ἐκτιθέμεθα, ἔστι τοιαύτη.

III (1) <Ἔστω> βάσις μῆκος ἔχουσα ὡς πῆχεος, πλάτος δὲ ὡς παλαιστῶν τεσσάρων, ὕψος δὲ ὡς παλαιστῶν τριῶν, κυμάτιον ἔχουσα περιτρέχον εἰς τε τὸ ἄνω καὶ τὸ κάτω μέρος. ἐπὶ δὲ τῶν γωνιῶν αὐτῆς ἐφέστηκε κιόνια τέσσαρα, ὕψος μὲν ἔχοντα ὡς παλαιστῶν $\bar{\eta}$, πλάτος δὲ παλαιστῶν

1-2 ὀργάνων... κινουμένων om. G 1-2 ἅμα τετάσθαι A G T^{pc} : ἅμα τε καὶ τετάσθαι T^{ac} : ἀνατετάσθαι M : ἀνατετάσθαι Ph 4 μηρύματα A T : μηρύσματα G : μὴ ρύματα M 5 κηρῷ A G M : κηρῶν T 6 ὅπως A G^{pcsl} M T : ὅπερ G^{ac} πραέως A G T : πράως Ab Ac Bb^{pcsl} La : πράος M Bb^{ac} 13 ἑτέρας A^{cp} M T : ἑτέρα G 14 δ' ἐν A^{pc} : ἐξ οὗ A^{ac} : δ' ἂν G : οὖν M T 14-15 ἀναστρέφεται Schmidt dub. in app. crit. : ἀναστρέφει a 15-16 ἐκτιθέμεθα A M T : ἐκτιθέμενα G 17 <Ἔστω> Schmidt πῆχεος a A^{ac} : πῆχεως A^{pcsl} Ea Lb Ld Pc Tb 19 εἰς τε M : εἵτε A G T 21 ὡς παλαιστῶν A G M : ὡς πα[***] T (ἡ post ὡς a secunda manu addito in mg.) $\bar{\eta}$ A G M Tb^{mg} : ἡ Ld : εἴκοσι Tb (in textu) : [***] T

for instruments which are not moved at the same time must not be pulled taut at the same time, but cords for <instruments> which are moved later must have slack parts.

(11) It is necessary to make the slackenings into hanks and glue them down with wax onto the appropriate place inside the case, so that the counterweight may stretch the cord gently while taking up the slack. Attention must also be paid to the cords, ensuring that each of them has been looped around its own instrument and not wound improperly; for, if one of them has been changed or wound improperly, the whole assemblage will come to a rest.

(12) The arrangements of the ancients must also be avoided, in order for the device to look more fresh; for it is possible, as previously mentioned, to create many different arrangements by employing the same methods. Whoever is devising a more pleasant arrangement will perform better in these things. The arrangement I set forth is such a one.

- III **(1)** <Let there be> a base having a length of approximately one cubit, a width of about four palms and a height of nearly three palms, with a moulding running around both its upper and its lower parts. Four column shafts, having a height of roughly 8 palms and a width of two palms, stand on the corners, with little base-mouldings placed at the

δύο, ἔχοντα ὑποκείμενα σπειρία καὶ τούτοις ἀρμοζούσας κεφαλὰς ἐπικειμένους. ἐπὶ δὲ τῶν κεφαλίων ἐπικείται <τι> καθάπερ ἐπιστύλιον κύκλῳ ὕψος ἔχον ὄγδοον τοῦ κίονος ὅλου, ὥς δακτύλων εἰ.

(2) κατὰ δὲ τοῦ ἐπιστυλίου κατέστρωται σανίδια καλύπτοντα τὴν ἐπάνω ἐπιφάνειαν, καὶ περικείται κύκλῳ κυμάτων. ἐπὶ δὲ τοῦ καταστρώματος ἐφέστηκε μέσον ναῖσκος στρογγύλος περιφανῆς ἔχων κίονας ἕξ. ἐπὶ δὲ τούτου πυργίον κωνοειδὲς ἐφέστηκε ἐντεταμένην ἔχον τὴν ἐπιφάνειαν, καθάπερ εἰρήσεται. 5 10

(3) ἐπὶ δὲ τῆς κορυφῆς ἐφέστηκε Νίκη ἐκπεπετακυῖα τὰς πτέρυγας καὶ ἐν τῇ δεξιᾷ χειρὶ στέφανον κατέχουσα. ἐν δὲ μέσῳ τοῦ ναῖσκου ζῳδιον Διονύσου ἐφέστηκε ἐν μὲν τῇ ἀριστερᾷ χειρὶ θύρσον κατέχον, ἐν δὲ τῇ δεξιᾷ σκύφον. παρακαθέζεται δὲ πανθηρίσκος πρὸς τοῖς τοῦ Διονύσου ποσίν. 15

(4) ἐν δὲ τοῖς ἔμπροσθεν καὶ τοῖς ὀπίσθεν μέρεσι τοῦ Διονύσου ἐπὶ τοῦ καταστρώματος βωμὸς ἐπικείται ἔχων ξύσματα {τῶν σανίδων} τεκτονικὰ ξηρὰ ὥστε εὐκαυστα εἶναι. κατὰ δὲ κίονα τῶν ἐν τῷ ναίσκῳ τοῦ Διονύσου παρῆστηκε ἐκτὸς τοῦ ναῖσκου Βάκχη διεσκευασμένη ὥς ἂν τις προαιρήται. 20

1 ἀρμοζούσας A G M : ἀρμοζούσης T 2 κεφαλίων A G T : κεφαλῶν M ἐπικείται om. M <τι> Schmidt dub. in app. crit. 3 an κύκλῳ <περιτρέχον>? ἔχον F (dub. in mg.) La : ἔχων a 4 εἰ a : δ' Schmidt dub. in app. crit. 5 τοῦ ἐπιστυλίου Schmidt dub. in app. crit. : τῶν ἐπιστυλίων a : τὸ ἐπιστύλιον R. Schöne κατέστρωται σανίδια A G M : κατέστρωται^{αν} T (ἴδια addito in mg.) 5-6 καλύπτοντα A G : διακαλύπτοντα M : διακαλύπτοντι T 8 περιφανῆς a P_C (in textu) P_G (in textu) : *περιφανῆς ed. princ. (*περιφερῆς in mg.) : περιφερῆς P_C (dub. in mg.) P_G (dub. in mg.) 9 κωνοειδὲς A G T : κωνοειδοῦς M 10 εἰρήσεται R. Schöne : εἴρηται a : εἴθισται Schmidt dub. in adn. crit. 11 ἐκπεπετακυῖα M : ἐκπεπετακυῖας A G : ἐκπεπετακούσας T 12 δὲ iterant A T 19 τῶν σανίδων del. Schmidt dub. in app. crit. 20 κίονα <ἕκαστον> R. Schöne

bottom and capitals in line with them placed at the top. On the capitals, all around, lies <something> like an architrave, with a height one-eighth of the whole column, approximately 5 fingers.

(2) On the architrave are laid boards covering its upper surface, and a moulding runs all around. On the covering stands prominently, in the middle, a circular shrine with six columns. On this stands a small cone-shaped cupola with a stretched surface, as will be said.

Fig. 1 (cf. XIII.3)

(3) On the peak stands a Nike with spread wings and holding a wreath in her right hand. In the middle of the shrine stands a figurine of Dionysus holding a thyrsus in his left hand, and a cup in his right. An effigy of a panther sits by Dionysus' side at his feet.

(4) In the spaces before Dionysus and behind him, on the covering, is an altar with woodwork shavings {made of boards}, dry enough to burn easily. At each of the columns of Dionysus' shrine, outside the shrine, stands a Bacchante prepared in whatever way one may choose.

- IV (1) Τούτων δὲ οὕτως ὑπαρχόντων ἐν ἀρχῇ τεθέντος τοῦ αὐτομάτου ἐπὶ τινα τόπον καὶ ἀποστάντων <ήμων> μετ' οὐ πολὺν χρόνον ὑπάξει τὸ αὐτόματον ἐπὶ τινα ὠρισμένον τόπον. καὶ στάντος αὐτοῦ ἀνακαυθήσεται ὁ κατάπροσθεν τοῦ Διονύσου βωμός. καὶ ἐκ μὲν τοῦ θύρσου τοῦ Διονύσου ἦτοι γάλα ἢ ὕδωρ ἐκπτυτισθήσεται, ἐκ δὲ τοῦ σκύφους οἶνος ἐκχυθήσεται ἐπὶ τὸν ὑποκείμενον πανθηρίσκον. 5
- (2) στεφανωθήσεται δὲ πᾶς ὁ παρὰ τοὺς τέσσαρας κίονας τῆς βάσεως τόπος. αἱ δὲ περικύκλω Βάκχαι περιελεύσονται χορεύουσαι περὶ τὸν ναῖσκον. καὶ ἦχος ἔσται τυμπάνων καὶ κυμβάλων. καὶ μετὰ ταῦτα σταθέντων τῶν ἡχων ἀποστραφήσεται τὸ τοῦ Διονύσου ζῳδῖον εἰς τὸ ἐκτὸς μέρος. ἅμα δὲ τούτῳ καὶ ἡ ἐπικειμένη τῷ πυργίῳ Νίκη συνεπιστραφήσεται. 10
- (3) καὶ πάλιν ὁ ἔμπροσθεν γεγωνὸς τοῦ Διονύσου βωμός, 15 πρότερον δὲ ὀπίσθιος ὑπάρχων ἀνακαυθήσεται. καὶ πάλιν ἐκ μὲν τοῦ θύρσου ὁ ἀναπτυτισμὸς ἔσται, ἐκ δὲ τοῦ σκύφους ἡ ἔκχυσις. καὶ πάλιν αἱ Βάκχαι χορεύσουσι περιερχόμεναι τὸν ναῖσκον μετὰ ψόφου τυμπάνων καὶ κυμβάλων. καὶ πάλιν σταθεισῶν αὐτῶν τὸ αὐτόματον ἀναχωρήσει εἰς τὸν ἐξ ἀρχῆς τόπον. 20

2 τόπον AGT : τρόπον M <ήμων> Schmidt dub. in app. crit. 3 ὑπάξει A^{pc} (ut videtur) : ἐπάξει A^{ac} GM : ἐπάξει T 4 κατάπροσθεν Ac Pb Pg Vd : κατα- πρόσθεν AG : κατὰ πρόσθεν MT 6 ἐκπτυτισθήσεται M^{2sl} : ἐκπιτυσθήσεται A G^{pc} M¹ T : ἐκπτυτσήσεται G^{ac} : ἐκπτυσθήσεται Aa Bc O 9 περικύκλω Diels : περὶ κύκλω a 9-10 περιελεύσονται AG : περιελάσσονται T : περιε- λάσσονται M^{ac} : περιελαύσσονται M^{pcsl} (ut videtur) 11 σταθέντων τῶν ἡχων a, hunc locum suspectum habuerunt viri docti : σταθέντων <τῶν ζῳδίων καὶ παυσθέντων> τῶν ἡχων H. Schöne : σταθ<εισῶν τῶν βακχῶν καὶ παυθ>έντων τῶν ἡχων Brinkmann : σταθεισῶν τῶν βακχῶν Schmidt dub. in app. crit. : an tantum παυσθέντων τῶν ἡχων? ἡχῶν R. Schöne dub. 12 διονύσου AGT : διονυσίου M 15 τοῦ Διονύσου Schmidt dub. in app. crit. : τῷ διονύσῳ a 16 ἀνακαυθήσεται AGT : ἀνακαμφθήσεται M 17 ἀναπτυτισμὸς M : ἀναπι- τυσμὸς AG : ἀναπιτυσμένος T 18 χορεύσουσι La : χορεύουσι a 18-19 περιερχόμεναι AGM T² : περιεχόμεναι T¹ 20-1 ἀναχωρήσει M : ἀναχωρίσει AGT

- IV** **(1)** With things in this way, at the beginning the automaton is put in a specific location and after a short time, while <we> keep away from it, it will move to some defined location. Once it has come to a standstill, the altar in front of Dionysus will flare up. Either milk or water will be made to spurt from Dionysus' thyrsus, while wine will stream out of his cup onto the panther lying beneath.
- (2)** Every place near the base's four columns will be adorned with garlands. The Bacchantes all around will go around the shrine dancing. There will be a clash of kettle-drums and cymbals. Afterwards, when the noise has stopped, the figurine of Dionysus will turn towards the outside. The Nike placed on the small cupola, too, will rotate at the same time with it.
- (3)** Then again, the altar that is in front of Dionysus, which before was behind him, will flare up. Again there will be the spurt from the thyrsus, and the stream from the cup. Again the Bacchantes will dance to the sound of kettle-drums and cymbals, going around the shrine. Again, once they have come to a stop, the automaton will move back to its starting point.

(4) καὶ οὕτως τέλος ἔξει ἢ ἐπιδείξεις. τοῖς δὲ εἰρημένοις μέτροις ἐχρησάμεθα ἀναγκαίως· μειζόνων γὰρ γεννηθέντων ὑπόνοιαν ἔξει τὸ ὄραμα ὥς ἐντός τινος ταῦτα δημιουργοῦντος. διὸ δὴ ἔν τε τοῖς ὑπάγουσι καὶ ἐν τοῖς στατοῖς αὐτομάτοις δεῖ φυλάσσεσθαι τὰ μεγέθη διὰ τὴν ἐσομένην ὑπόνοιαν. τῆς οὖν διαθέσεως εἰρημένης ἐξῆς τὴν κατασκευὴν τῶν κατὰ μέρος ἐν αὐτῇ ποιησόμεθα. 5

v (1) Οἱ μὲν οὖν πρὸ ἡμῶν τὴν ἐπὶ μιᾶς ὁδὸν τῆς τε πορείας καὶ τῆς ἀποπορείας παρέδωκαν ἡμῖν καὶ ταύτην κακοπαθῆτε καὶ ἐπικίνδυνον· σπάνιον γὰρ ἐπιτυχεῖν κατακολουθοῦντα ταῖς ὑπ' αὐτῶν ἀναγεγραμμέναις μεθόδοις, ὥς ἔστι φανερόν τοῖς πεπειραμένοις αὐτῶν. 10

(2) ἡμεῖς δὲ ὑποδείζομεν, ὥς ἔστι τὴν ἐπ' εὐθείας πορείαν καὶ ἀποπορείαν γίνεσθαι εὐκόπως τε καὶ ἀκινδύνως, ἔτι δὲ καὶ ὥς <ἔστι> τὸ πλινθίον ἢ τὸ ζῳδίον κατὰ κύκλου τοῦ δοθέντος φέρεσθαι, οὐ μὴν ἀλλὰ καὶ ἐν παραλληλογράμμῳ ὀρθογωνίῳ τῷ δοθέντι φέρεσθαι. 15

(3) καὶ πρότερον, ὥς ἐπ' εὐθείας, ἐροῦμεν. ἔστω γάρ τι πλινθίον τὸ $\overline{αβγδ}$, ἐν ᾧ ἄξων διακεῖσθω ὁ $\overline{εζ}$ ἐν κνώδαξι στρεφόμενος, ἐμβεβηκῶς εἰς πυελίδας οὔσας ἐν τοῖς τοῦ πλινθίου τοίχοις. τῷ δὲ ἄξονι συμφυεῖς ἔστωσαν δύο τρο- 20

2 γὰρ γεννηθέντων G M T : γὰρ (sic) γε γεννηθέντων A (post γε. duabus litteris erasis)
5 φυλάσσεσθαι M : φιλάσσεσθαι A G T 9 τῆς om. M ἀποπορείας Ab^{pcl}
Bb La Lc (dub. in mg.) Pc Pe Pg : εὐποπορείας A T : εὐπορείας G M Ab^{ac} 11 ἔστι
A G M T^{2mg} : ἐπι T¹ 12 πεπειραμένοις A G M : πεπειρασμένοις T 13 ἐπ'
εὐθείας Ab^{pc} Pe : ἐπευθείας A^{ac} : ἐπαληθείας A^{pcl} G T : ἐπ' ἀληθείας M Ab^{ac}
14 ἀποπορείαν Pe Pg : εὐποπορείαν A^{ac} : εὐπορείαν A^{pc} G M T δὲ scripsi :
τε a 15 ὥς del. Hildebrandt <ἔστι> Schmidt τι πλινθίον {ἢ τὸ ζῳδίον}
Schmidt dub. in app. crit. κύκλου A G T : κύκλον M 16 οὐ A G : καὶ M
T 18 ἐπ' M : ἐπὶ A G T τι a : τὸ La 19 κνώδαξι A G : κνώδακι M T
20 ἐν τοῖς G M : ἐντοι A : ἔν τοι T τοῦ om. M 21 συμφυεῖς M : συμφυῆς
A G T

(4) In this way the performance will come to an end. I employed the mentioned dimensions out of necessity; for if they are any larger, the sight will arouse suspicion as though someone was contriving these movements from the inside. Then, as a result, in both the mobile and the stationary automata, one must watch out for great dimensions, because of the suspicion that will arise. So, the arrangement having been described, I will next construct its parts one by one.

v (1) So, those who came before me have handed down to us a way of effecting forward and backward motion along a single <line>, though troublesome and involving danger; for success is rarely achieved by following the methods they have written down, as is clear to those who have tried them.

(2) I, by contrast, will show that forward and backward motion along a straight line can take place both easily and without danger and, in addition, that the case or the figurine <can> be carried on a given circle, and, what is more, even along a given rectangular parallelogram.

(3) First, I will talk about <motion> along a straight line. Let there be a certain case, $\overline{\alpha\beta\gamma\delta}$, in which let there be placed an axle, $\overline{\epsilon\zeta}$, turning on pivots and fitted into sockets which are on the sides of the case. Let there be two equal

Figs. 4a-b

χοὶ ἴσοι οἱ $\overline{\eta\theta}$, $\overline{\kappa\lambda}$ τὰς περιφερείας εἰργασμένοι φακοειδεῖς·
καὶ <ἔστω> κατὰ μέσον τὸν ἄξονα ἐξελίκτρα ἢ μὲν καὶ
αὐτὴ συμφυῆς τῷ ἄξονι, περὶ ἣν ἡ σπάρτος ἐπειληθήσεται.

(4) ταύτη δὲ συμφυῆς ἔστω τύλος ὁ ξ , περὶ ὃν ἡ τῆς σπάρ-
του ἀγκύλη περικεῖσεται. ἕτερος δὲ ἔστω τροχὸς κατὰ 5
μέσσην τὴν $\overline{\gamma\delta}$ πλευρὰν ὁ $\overline{\sigma\pi}$ ἐν πῆγματι πολευόμενος τῷ
 $\overline{\rho\sigma\tau\upsilon}$ περὶ ἄξονα τὸν $\overline{\phi\chi}$ μικρὸν σφόδρα. οὕτως δὲ ἐνηρμό-
σθωσαν οἱ ἄξονες τῶν τροχῶν, ὥστε τὸ πλινθίον ἀκλινὲς
καθεστάναι κατὰ πᾶν μέρος. τῆς οὖν ἀγκύλης τῆς σπάρτου
περιβληθείσης περὶ τὸν ξ τύλον, ἐπειλείσθω περὶ τὴν ἐξε- 10
λίκτραν ἡ σπάρτος.

(5) καὶ σύριγγος ἐπικειμένης τετραγώνου πρὸς ὀρθὰς κατὰ
μέσον τὸ πλινθίον, ἡ ἑτέρα ἀρχὴ τῆς σπάρτου διὰ τροχί-
λου ἀποδεδόσθω εἰς τὸ ἄνω μέρος τῆς σύριγγος καὶ ἐξή-
φθω εἰς μολιβοῦν βάρος ἐνὸν ἐντὸς ἐν τῇ σύριγγι. οὐκοῦν 15
ἐάν τις ἀφῇ τὸ βάρος ἐν τῇ σύριγγι καταφέρεσθαι, τενεῖ
τὴν σπάρτον. αὕτη δὲ ἀπειλουμένη ἀπὸ τῆς ἐξελίκτρας
ἐπιστρέψει τοὺς $\overline{\eta\theta}$, $\overline{\kappa\lambda}$ τροχοὺς· οὗτοι δὲ κατὰ τοῦ ἐδά-
φους κυλιόμενοι ἄξουσι τὸ πλινθίον, ἄχρις ἂν ἦτοι ἡ ἀγ-
κύλη ἐκπέσῃ ἀπὸ τοῦ τύλου ἢ τὸ βάρος ἐπικαθίσῃ τινί. 20

VI (1) Ἡ μὲν οὖν πορεία γίνεται τὸν εἰρημένον τρόπον, ἡ δὲ
ἀποπορεία οὕτως. ἐπειληθείσης γὰρ τῆς σπάρτου περὶ τὴν

1 οἱ M : ἡ AGT φακοειδεῖς MbPdPg^{pc}Ph : φασκοειδεῖς AGT Pg^{ac} :
φανοειδεῖς M 2 <ἔστω> Schmidt dub. in app. crit. κατὰ AGMT² : μετὰ
T¹ 3 ἐπειληθήσεται AG : ἐπιλειφθήσεται M : [***] T 4 τύλος AGM^{pcsl} T
: στόλος M^{ac} ξ Schmidt : νξ a 5 δὲ ἔστω AGM : δ' ἔστω T 6 $\overline{\sigma\pi}$
Schmidt : $\overline{\rho\pi}$ a πῆγματι GM^{pcsl} : πῆγμασι Pg^{mg} : πῆγματι Pg^(in textu) : πῆγματι
M^{ac} T : πῆγματα A^{cp} πολευόμενος AGT : πορευόμενος M 7 $\overline{\rho\sigma\tau\upsilon}$ AGT :
 $\overline{\rho\sigma}$ $\overline{\tau\omega}$ M 8 τὸ AGT : τὸν M 10 ξ Schmidt : νξ a 14 ἀποδεδόσθω AGT
: ἀποδεδέσθω M 16 καταφέρεσθαι Schmidt dub. in app. crit. : κάτω φέρε-
σθαι a τενεῖ Schmidt dub. in app. crit. : τείνει a 19 ἂν GMT : ἀμὸν A^{cp}
ἢ om. T 21 ἡ² M : εἰ AGT

wheels, $\overline{\eta\theta}$ and $\overline{\kappa\lambda}$, attached to the axle, with their circumferences worked so as to be lentil-shaped; <let there be> a bobbin in the middle of the axle, $\overline{\mu\nu}$, and <let> this <be> attached to the axle. The cord will be wound around this bobbin.

(4) To this [the bobbin] let there be attached a knob, $\overline{\xi}$, around which the loop of the cord will lie. Let there be another wheel, $\overline{o\pi}$, in the middle of side $\overline{\gamma\delta}$, rotating within a frame, $\overline{\rho\sigma\tau\nu}$, around a very small axle, $\overline{\phi\chi}$. Let the axles of the wheels be adjusted in such a way that the case may stand level in every part. So, after the loop of the cord has been put around the knob $\overline{\xi}$, let the cord be wound around the bobbin.

Fig. 5a

(5) With a rectangular tube placed perpendicularly in the middle of the case, let the other end of the cord pass through a pulley towards the upper part of the tube and be fastened to a lead weight that is inside the tube. So, if someone lets the weight go down in the tube, they will stretch the cord. This will turn the wheels $\overline{\eta\theta}$ and $\overline{\kappa\lambda}$ by being unwound from the bobbin; these will drive the case by rolling along the ground, until either the loop falls off the knob or the weight comes to rest on something.

Fig. 2

VI (1) Therefore, forward motion occurs in the manner described, and backward motion as follows. Once the cord has been wound to a certain extent around the bobbin,

ἐξελίκτρان ἐπί τι μέρος, περιτεθείσα περὶ τὸν ξ τύλον τὰ ἐναντία ἐπειλείσθω τῇ πρότερον <ἐπειλήσει> περὶ τὴν ἐξελίκτρان. εἶτα ἀποδεδόσθω ὁμοίως εἰς τὴν λείαν κρίκου συνεχομένου αὐτῇ. πάλιν οὖν καταφερομένη ἡ λεία ἀπειλήσει τὴν πρώτην ἐπείλῃσιν, καὶ τὸ πλινθίον πορευθήσεται. 5

(2) εἶτα ἀποστᾶσα ἀπὸ τοῦ τύλου εἰς τὰ ἐναντία ἐπιστρέψει τοὺς τροχούς, καὶ οὕτως ἔσται ἡ ἀποπορεία τοῦ πλινθίου. ἐὰν δὲ βουλώμεθα πορευθὲν τὸ πλινθίον στῆναι ἐπὶ τινα χρόνον καὶ οὕτως τὴν ἀποπορείαν ποιήσασθαι, ἐπειλήσαντες τὴν σπάρτον καὶ περιβαλόντες περὶ τὸν τύλον οὐκ εὐθέως τὰ ἐναντία ἐπειλήσομεν, ἀλλὰ μηρυμάτιον ποιήσαντες καὶ προσκολλήσαντες {ἐπειλήσομεν} ἐπὶ τὴν ἐξελίκτρان καὶ πάλιν τὰ ἐναντία ἐπειλήσαντες ἀποδώσομεν εἰς τὴν λείαν, καὶ ἔσται τὸ προκείμενον. 10 15

(3) ἐὰν δὲ καὶ πολλάκις βουλώμεθα πορεύεσθαι τε καὶ ἀποπορεύεσθαι τὸ πλινθίον, πλεονάκις καὶ τὰς ἐναλλάξ ἐπειλήσεις ποιησόμεθα καὶ τὰ διαστήματα ἡλίκαι ἂν προαιρώμεθα καὶ τοὺς τῶν {δὲ} μονῶν χρόνους ποιήσομεν διὰ τῶν μηρυμάτων ἡλίλους ἂν προαιρώμεθα. 20

1 περιτεθείσα AGM T^{2mg} : τεθείσα T¹ : περιτεθείσα <ἄλλη> Prou, obl. Schmidt ξ Schmidt : vξ a 2 ἐπειλείσθω AGT : ἐπικείσθω M <ἐπειλήσει> Schmidt dub. in app. crit. 3-4 ἀποδεδόσθω... καταφερομένη om. T¹ (pro his verbis habet ἀποδεμένη) : add. T^{2mg} ἀποδεδόσθω AGM^{2sl} : ἀποδιδόσθω M¹ 4 συνεχομένου AGM : [***] T : συγκεκριμένου Schmidt dub. in app. crit. 8 ἀποπορεία G : ἀποπειρεία AT : ἀπορεία M 9 τὸ πορευθὲν M 10 τὴν La : τὴν A : τὴν GMT 11 περιβαλόντες AM : περιβαλλόντες GT : περιβάλλοντες PaPf 12 ἐπειλήσομεν Brinkmann : ἐπειλησόμεθα a, rec. Schmidt μηρυμάτιον a : μηρυμάτια Schmidt dub. in app. crit. 13 προσκολλήσαντες Ab Ac Bb La Lc Ld R² Ta Tb^{mg} : προσκώλυσαντες AGT ed. princ. : προσκολάσαντες M : προσκωλύσαντες Prou ἐπειλήσομεν del. Brinkmann : om. Pa 15 an καὶ <οὕτως>? 16-20 ἐὰν... προαιρώμεθα interpolata esse cens. Schmidt, obl. Olivieri 17 τὸ AGT : τὸν M 18-19 καὶ... ποιήσομεν add. G^{mg} ἡλίκαι R^{mg} : ἡνίκαι a 19 δὲ μονῶν Brinkmann, δὲ delevi : δαιμόνων a χρόνους a : χοροὺς Schmidt dub. in app. crit.

having been put around the knob ξ , let it be wound around the bobbin in the direction opposite to the preceding <one>. Subsequently, let it be likewise attached to the counterweight with a ring joined to it. So again, the counterweight will unroll the first winding while descending, and the case will move.

Fig. 5b

(2) Then, after it [the cord] has detached from the knob, it will turn the wheels in the opposite direction, and thus the case will come back. However, if we want the case, once it has travelled, to stand still for some time and move back in this way, we will wind the cord and put it around the knob without winding it the other way around immediately. Instead, after we have formed a hank, glued it onto the bobbin and wound <the cord> again contrariwise, we will attach it to the counterweight, and what has been said before will happen.

Fig. 5c

(3) If we also want the case to move forward and backward many times, we will make alternate windings more frequently and the intervals <between them> the size we may choose; we will also regulate the timings of the pauses by means of hanks of the length we may choose.

(4) νοείσθω δὲ καὶ κατὰ κρόταφον τὸ πλινθίον σὺν τῇ σύριγγι ὀρώμενον, καὶ ἔστω πλινθίον μὲν τὸ $\overline{\psi\omega}$, ἐξελίκτρα δὲ ἡ $\overline{\varsigma}$, σύριγξ δὲ ἡ $\overline{\tau}$, σπάρτος δὲ ἡ $\overline{\alpha\beta}$ περὶ τροχίλον {δὲ} περικειμένη τὸν $\overline{\Gamma}$, λεία δὲ ἡ $\overline{\delta}$, ὁ δὲ ἐν αὐτῇ κρίκος ὁ $\overline{\epsilon}$.

5

VII (1) Ἡ δὲ ἐπὶ κύκλου πορεία γίνεται τόνδε τὸν τρόπον.

ἔστω γὰρ κύκλος, καθ' οὗ φέρεσθαι δεῖ τὸ πλινθίον, ὁ $\overline{\alpha\beta\gamma}$, οὗ κέντρον τὸ $\overline{\delta}$. καὶ διήχθω τις ἡ $\overline{\alpha\delta}$, καὶ <πρὸς> ταύτην ὀρθῇ ἀπὸ τοῦ $\overline{\alpha}$ ἡ $\overline{\epsilon\alpha\zeta}$. ἡ δὲ $\overline{\epsilon\zeta}$ διάμετρος ἔστω ἑνὸς τῶν τριῶν τροχῶν, ἡλίκου ἂν προαιρώμεθα. διχοτομία δὲ αὐτῆς ἔστω τὸ $\overline{\alpha}$, καὶ ἐπεζεύχθωσαν αἱ $\overline{\delta\epsilon}$, $\overline{\delta\zeta}$.

10

(2) τῷ δὲ μεγέθει τοῦ ἄξονος τῶν τροχῶν ἴση ἔστω ἡ $\overline{\alpha\eta}$, καὶ τῇ $\overline{\epsilon\zeta}$ παράλληλος ἡ $\overline{\eta\theta\kappa}$. τὸ δὲ πλινθίον ἔστω τὸ $\overline{\mu\lambda\nu\zeta}$ παράλληλον ἔχον τὴν $\overline{\nu\zeta}$ τῇ $\overline{\alpha\delta}$. καὶ ἤχθω τις ἑτέρα ἡ $\overline{\delta\sigma}$, καὶ ταύτῃ πρὸς ὀρθὰς ἡ $\overline{\pi\rho}$ δίχα τεμνομένη ὑπὸ τοῦ $\overline{\sigma}$. ἔσονται δὲ αἱ τῶν τροχῶν θέσεις κατὰ διαμέτρους τὰς $\overline{\epsilon\zeta}$, $\overline{\theta\kappa}$, $\overline{\pi\rho}$, ἄξονες δὲ αὐτῶν οἱ $\overline{\tau\upsilon}$, $\overline{\sigma\chi}$.

15

(3) οὕτως οὖν τετάχθωσαν οἱ τροχοὶ τῇ θέσει, ὥστε ἐστὸς ἐπ' αὐτῶν τὸ πλινθίον ἰσορροπεῖν. οἱ ἄρα κνώδακες τῶν ἀξόνων ἔσονται πρὸς τοῖς $\overline{\tau}$, $\overline{\upsilon}$, $\overline{\sigma}$, $\overline{\chi}$ σημείοις. πάλιν οὖν μεταξὺ τῶν $\overline{\alpha}$, $\overline{\eta}$ ἡ ἐξελίκτρα κείσθω, περὶ ἣν ἡ σπάρτος

20

3 σύριγξ M : σύριξ AGT 4 δὲ¹ del. Schmidt περικειμένην a : περικείμενον F : correxi τὸν Schmidt : τὴν a 5 ἡ AGT : ῥ M 7 ὁ Schmidt dub. in app. crit. : τὸ a 8 <πρὸς> supplevi 9 ταύτην scripsi : ταύτῃ AGM : [***] T ὀρθῇ a : πρὸς ὀρθὰς Schmidt dub. in app. crit. 11 δὲ AT : δὲ G^{op} M 12 μεγέθει AGM : μεγέθη T 13 τῇ ed. princ. : τὸ a ἡθκ a : ἡθη Ld : θκ M : ηκθ Ph^{mg} : θηκ Schmidt dub. in app. crit. 14 τὴν νζ <πλευρὰν> Schmidt dub. in app. crit. 15 τοῦ σ a : τοῦ σ Aa : τῆς δσ Schmidt dub. in app. crit. 18 οὕτως AGT : ἔτι M ἐστὸς AT : ἐστὼς G : ἐκτὸς M 19 ἐπ' αὐτῶν AG : ἐπ' αὐτὸν T : ὑπ' αὐτὸν M τὸ AGT : τὸν M κνώδακες πτελίδες Ph^{mg} 20 an {σημείοις}? 21 ἡ¹ om. M

(4) Let the case, along with the tube, be conceived as seen from the side, and let there be a case, $\overline{\psi\omega}$, a bobbin, $\overline{\zeta}$, a tube, $\overline{\tau}$, a cord $\overline{\alpha\beta}$ lying around a pulley, $\overline{\Gamma}$, a counterweight, $\overline{\delta}$, and a ring on it, $\overline{\varepsilon}$.

Figs. 6a-b

vii (1) The motion in a circle occurs in the following way.

Figs. 7a-b (cf. VIII.1)

Let there be a circle along which the case must be carried, $\overline{\alpha\beta\gamma}$, with its centre $\overline{\delta}$. Let a certain <line>, $\overline{\alpha\delta}$, be drawn, and let a <line> $\overline{\varepsilon\alpha\zeta}$ be drawn perpendicular <to> it at $\overline{\alpha}$. Let the diameter $\overline{\varepsilon\zeta}$ be <the diameter> of one of the three wheels, of whatever size we may choose. Let its point of bisection be the <point> $\overline{\alpha}$, and let the <lines> $\overline{\delta\varepsilon}$ and $\overline{\delta\zeta}$ be joined.

(2) Let a <line> $\overline{\alpha\eta}$ be equal to the size of the axle of the wheels, and a <line> $\overline{\eta\theta\kappa}$ parallel to $\overline{\varepsilon\zeta}$. Let there be a case, $\overline{\mu\lambda\nu\xi}$, with the <line> $\overline{\nu\xi}$ parallel to $\overline{\alpha\delta}$. Let another certain <line>, $\overline{\delta\theta}$, be drawn, and <let> a <line> $\overline{\pi\rho}$, which is bisected by the <point> $\overline{\theta}$, <be drawn> perpendicular to it. The positions of the wheels will then be along the diameters $\overline{\varepsilon\zeta}$, $\overline{\theta\kappa}$ and $\overline{\pi\rho}$, and their axles will be $\overline{\tau\nu}$ and $\overline{\theta\chi}$.

(3) So, let the wheels be arranged in such a position that the case set on them may be in equilibrium. The pivots of the axles will then be at the points $\overline{\tau}$, $\overline{\nu}$, $\overline{\theta}$ and $\overline{\chi}$. So again, let the bobbin around which the cord is wound be placed

ἐπειλείται, καὶ τὰ αὐτὰ γεγονέντω τοῖς ἔμπροσθεν εἰρημέ-
νοις. καὶ οὕτως ἐνεχθήσεται κατὰ τοῦ εἰρημένου κύκλου
τὸ πλινθίον.

- VIII** (1) Ἐὰν γὰρ κῶνος κυλίηται κατὰ ἐπιπέδου, ἡ μὲν βάσις
αὐτοῦ γράψει κύκλον, οὗ ἡ ἐκ τοῦ κέντρου ἴση ἐστὶ τῇ τοῦ 5
κῶνου πλευρᾷ, ἡ δὲ κορυφή αὐτοῦ μενεῖ ἀκίνητος κέντρον
οὔσα τοῦ εἰρημένου κύκλου. οἱ δὲ $\overline{\epsilon\zeta}$, $\overline{\theta\kappa}$, $\overline{\pi\rho}$ τροχοὶ ἐν
κῶνοις εἰσὶ δυσὶν, ὧν βάσεις μὲν οἱ $\overline{\epsilon\zeta}$, $\overline{\pi\rho}$ κύκλοι, κορυφή
δὲ τὸ $\overline{\delta}$ σημεῖον.
- (2) ὅτι δὲ οἱ κῶνοι οἱ ἰσοσκελεῖς κυλιόμενοι κύκλους τε 10
γράφουσι καὶ τὴν κορυφὴν ἔχουσιν ἀκίνητον, φανερόν·
κείμενος γὰρ <κῶνος> ἐν τῷ ἐπιπέδῳ καὶ βεβηκὼς κατὰ
τὴν ἑαυτοῦ πλευρὰν ἰσόρροπός ἐστιν ἑαυτῷ· τέμνεται γὰρ
ὑπὸ τοῦ διὰ τῆς πλευρᾶς ἐκβαλλομένου ἐπιπέδου ὀρθοῦ
πρὸς τὸν ὀρίζοντα δίχα. ὅταν δὲ ἑτέρα δύναμις κατακρα- 15
τηθεὶς κυλίηται, ἕκαστον τῶν ἐν τῇ ἐπιφανείᾳ αὐτοῦ ἡμι-
κυκλίων τῶν ἐπὶ τὰ αὐτὰ τῇ ἴσῃ δυνάμει κατακρατεῖ τοῦ
λοιποῦ τοῦ αὐτοῦ κύκλου ἡμικυκλίου, καὶ οὕτως τοῦτο
κινεῖται.
- (3) ἐπινοουμένων δὲ τῶν ἡμικυκλίων {τῶν} ἄχρι τῆς κο- 20
ρυφῆς, οὐ λείπεται πρὸς τῇ κορυφῇ οὔτε ἡμικύκλιον οὔτε
ἄλλο τι διαστατόν. διὸ ἡ κινούσα δύναμις μηκέτι ἔχουσα
τίνι κατακρατήσῃ τοῦ ἐπὶ τὰ ἕτερα κειμένου μέρη, ἀδυνα-
τεῖ κινῆσαι τὴν κορυφὴν ἐν τῇ κατὰ τὴν ἐπιστροφὴν κινή-

2 κύκλου AG : κυκλίου MT 4 κῶνος <ἰσοσκελεῖς> H. Schöne 5 γράψει
A^{pc} G : γράφει A^{ac} MT οὗ AG : ἡ M : [***] T 6 μενεῖ Schmidt dub. in
app. crit. : μένει AGM : μ[***] T 8 βάσεις Schmidt : βάσις a οἱ Schmidt
: ἡ a 10 κῶνοι M : κῶνοι AGT 11 καὶ om. T¹ : add. T^{2mg} 12 <κῶνος>
supplevi τῷ <παρὰ τὸν ὀρίζοντα> ἐπιπέδῳ vel τῷ ἐπιπέδῳ <παραλλήλῳ τῷ
ὀρίζοντι> Schmidt dub. in app. crit. 13 γὰρ om. MT 14 ἐκβαλλομένου A
GT : ἐμβαλλομένου M 15 ὅταν AG : οὕτως MT 17 ἴση a : κινούση
Schmidt dub. in app. crit. 20 τῶν¹ om. MT τῶν² delevi : suspectum
habuerat Brinkmann 22 διὸ om. M ἡ A^{pc} GMT : καὶ ἡ A^{ac} 23 κειμένου
AMT : κινουμένου G

between $\bar{\alpha}$ and $\bar{\eta}$, and let the same happen as has been said before. The case will thus be carried along the said circle.

- VIII** **(1)** If a cone rolls on a plane, its base will describe a circle, whose radius is equal to the side [a generatrix] of the cone, and its vertex will remain motionless, being the centre of the said circle. The wheels $\bar{\epsilon\zeta}$, $\bar{\theta\kappa}$ and $\bar{\pi\rho}$ are inside two cones, whose bases are the circles $\bar{\epsilon\zeta}$ and $\bar{\pi\rho}$, and whose vertex is the point $\bar{\delta}$.
- (2)** It is clear that the cones which are isosceles, as they roll along, describe circles and have their vertex motionless. For, when <a cone> lies on the plane and stands on its side, it is in equilibrium with itself; it is, in fact, bisected by the plane that is generated through the side perpendicularly to the horizon. When it rolls, having been overcome by another force, each of the semicircles on its surface which are on the same side overcomes with equal force the remaining semicircle of the same circle, and thus this moves.
- (3)** If the semicircles are conceived <as reaching> up to the vertex, there is no semicircle left in the apex, nor anything else with dimensions. For this reason, since the motive force no longer has any means to overcome what lies on the other side, it cannot move the apex during the

σει, εἰ μὴ ἄρα κατὰ τὸν προωσμὸν ἢ ἐπικράτησις αὐτῆς γίνεται.

IX (1) Ἡ δὲ ἐν τῷ ὀρθογωνίῳ παραλληλογράμῳ πορεία τοῦ πλινθίου ἔσται τόνδε τὸν τρόπον.

ἔστω γὰρ πλινθίον τὸ $\overline{αβγδ}$, ἐν ᾧ ἄξων ἔστω ὁ $\overline{εζ}$ συμ- 5
φυεῖς ἔχων τροχούς τοὺς $\overline{ηθ}$, $\overline{κλ}$. ὁ δὲ τρίτος τροχὸς ἔστω ὁ $\overline{μν}$. δι' ὧν ἢ τε πορεία καὶ ἡ ἀποπορεία γίνεται, ὡς προγέ-
γραπται. ἔστω δὲ καὶ ἕτερος ἄξων ὁ $\overline{ξο}$ συμφυεῖς ἔχων
τροχούς τοὺς $\overline{πρ}$, $\overline{στ}$ καὶ ὁμοίως <***> τὸν $\overline{υφ}$.

(2) ἐπάνω δὲ ἔστω ὁ $\overline{ξο}$ ἄξων τοῦ $\overline{εζ}$ ἄξονος ἀπέχων ἀπὸ 10
τοῦ $\overline{εζ}$ ἄξονος ἱκανόν. δυνάσθωσαν δὲ οἱ $\overline{πρ}$, $\overline{στ}$ τροχοὶ σὺν
τῷ $\overline{ξο}$ ἄξονι μετεωρίζεσθαι καὶ ταπεινοῦσθαι, ὡς ἐξῆς
ἐροῦμεν· ὁμοίως δὲ καὶ ὁ $\overline{υφ}$ τροχός. ἐὰν οὖν καταβιβάσω-
μεν τοὺς $\overline{πρ}$, $\overline{στ}$, $\overline{υφ}$ τροχούς, ὥστε ἐπικαθίσαι τῷ ἐδάφει,
μετεωρισθήσονται οἱ $\overline{ηθ}$, $\overline{κλ}$, $\overline{μν}$ τροχοὶ ἀπὸ τοῦ ἐδάφους, 15
καὶ ποιήσεται τὴν πορείαν τὸ πλινθίον διὰ τῶν $\overline{πρ}$, $\overline{στ}$, $\overline{υφ}$.

(3) καὶ ἀνασπασθέντος τοῦ $\overline{ξο}$ ἄξονος, ὥστε πάλιν τοὺς
 $\overline{ηθ}$, $\overline{κλ}$, $\overline{μν}$ ἐπικαθίσαι τῷ ἐδάφει, {καὶ} δι' αὐτῶν τὴν ἐτέ-
ραν τοῦ παραλληλογράμμου πλευρὰν πορευθήσεται τὸ
πλινθίον. εἴτα πάλιν στάντος αὐτοῦ καταβιβασθήσονται οἱ 20
 $\overline{πρ}$, $\overline{στ}$, $\overline{υφ}$, καὶ πάλιν δι' αὐτῶν τὴν ἐτέραν τοῦ παραλληλο-
γράμμου πλευρὰν ἐνεχθήσεται τὸ πλινθίον. καὶ τούτου
ἐναλλάξ γινομένου, ὅσάκις ἐὰν προαιρώμεθα ἐλεύσεται
ἐπὶ τὸ παραλληλόγραμμον τὸ πλινθίον.

1 προωσμὸν AT : προωρισμὸν GM¹ : προορισμὸν M^{2sl} 6 τοὺς ed. princ. :
τὸν a 7 ἢ M : om. AGT 9 τοὺς ed. princ. : τὸν a lacunam statui
secutus Schmidt : <τρίτος τροχός> Schmidt dub. in app. crit., mutato τὸν in ὁ :
an <ἄξων συμφυῇ ἔχων τροχόν> vel <ἄξων ἔχων συμφυῇ τροχόν> vel sim.?
13-14 καταβιβάσωμεν GM : καταβιβάσωμεν A : καταβιβάσαμεν T 15 $\overline{ηθ}$
AGT : $\overline{κθ}$ M 18 καὶ del. Brinkmann 19 πορευθήσεται Schmidt : πορευ-
θῆναι a 21 αὐτῶν GMT : αὐτὸ A 24 τὸ παραλληλόγραμμον a : τοῦ
παραλληλογράμμου Schmidt dub. in app. crit.

rotational motion, unless perhaps it is overcome by a forward propulsion.

- IX (1) The motion of the case along a rectangular parallelogram will occur in the following way.

Figs. 8a-b, 9 (cf. X.1-2)

Let there be a case, $\overline{\alpha\beta\gamma\delta}$, in which let there be an axle, $\overline{\varepsilon\zeta}$, with wheels attached to it, $\overline{\eta\theta}$ and $\overline{\kappa\lambda}$; let there be the third wheel, $\overline{\mu\nu}$. The forward and backward motion takes place by means of these wheels, as has been written before. Let there be another axle, $\overline{\xi\omicron}$, with wheels attached to it, $\overline{\pi\rho}$ and $\overline{\sigma\tau}$, and likewise $\langle^{***}\rangle$, $\overline{\upsilon\phi}$.

(2) Let the axle $\overline{\xi\omicron}$ be above the axle $\overline{\varepsilon\zeta}$, at a sufficient distance from it. Let the wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$ have the potential to be raised and lowered together with the axle $\overline{\xi\omicron}$, as I will explain next; and likewise the wheel $\overline{\upsilon\phi}$. Thus, if we lower the wheels $\overline{\pi\rho}$, $\overline{\sigma\tau}$ and $\overline{\upsilon\phi}$, so that they rest on the ground, the wheels $\overline{\eta\theta}$, $\overline{\kappa\lambda}$ and $\overline{\mu\nu}$ will be raised from the ground, and the case will effect its motion by means of $\overline{\pi\rho}$, $\overline{\sigma\tau}$ and $\overline{\upsilon\phi}$.

(3) When the axle $\overline{\xi\omicron}$ has been pulled up, so that again $\overline{\eta\theta}$, $\overline{\kappa\lambda}$ and $\overline{\mu\nu}$ rest on the ground, {and} the case will move over the other side of the parallelogram by means of them. Then again, once it has stopped, $\overline{\pi\rho}$, $\overline{\sigma\tau}$ and $\overline{\upsilon\phi}$ will be lowered, and again the case will be carried along the other side of the parallelogram by means of them. When this happens in an alternate sequence, the case will go along the parallelogram as many times as we may choose.

(4) πορείας δὲ μονὰς ποιήσεται ὥς ἂν προαιρώμεθα, διὰ τε τῶν τῆς σπάρτου ἐπειλήσεων καὶ τῶν χαλασμάτων. ἵνα οὖν μὴ τὸ βάρος τῆς λείας σφοδρότερον καταφερόμενον ἐν τῇ σύριγγι ταχεῖαν ποιῇται τὴν τοῦ πλινθίου κίνησιν, ἐμβαλοῦμεν ἐν τῇ σύριγγι κοῦφόν τι καὶ λεπτὸν καὶ γλί- 5 σχρον, οἷον κέγχρον ἢ νᾶπυ, εἰς δὲ ἐπικείσεται ἡ λεία.

(5) τρυπήσομεν δὲ τὸν πυθμένα τῆς σύριγγος συμμέτρῳ τρυπήματι, ὃ κλειθρίῳ ἀνοιχθήσεται τε καὶ κλεισθήσεται ἐνδεθέντι σπάρτῳ, ἥς τὸ ἄκρον ἐκτὸς διὰ τρυπήματος φα- 10 νερόν ἡμῖν ἔσται, ὅπως ὅταν βουλώμεθα κινεῖσθαι τὸ πλινθίον, ἐπιλαμβανόμενοι τῆς σπάρτου {οὐ} λεληθότως ἀνοίξωμεν τὸ κλειθρίον. καὶ οὕτως τῆς κέγχρου ῥεοῦσης ἡρέμα εἰς τὴν ὑποκειμένην βάσιν, κινεῖται τὸ πλινθίον.

(6) ἵνα δὲ μὴ ἅμα τῷ ἀνοιχθῆναι τὸ κλειθρίον ὀρμὴν τὸ πλινθίον λάβῃ, ἔξει μικρὸν χαλασμάτιον ἢ σπάρτος, ὅπως 15 ὀλίγης κέγχρου ἐκρυσίσης τότε ταθεῖσα κινήσει τὸ πλινθίον. ὥς δὲ δεῖ τοὺς τρεῖς τροχοὺς μετεωρίζεσθαι τε καὶ ταπεινοῦσθαι ἐναλλάξ, νῦν ἐροῦμεν.

Χ (1) Ἔστωσαν οἱ εἰρημένοι τροχοὶ τρεῖς οἱ $\overline{αβ}$, $\overline{γδ}$, $\overline{εζ}$, τῶν δὲ $\overline{αβ}$, $\overline{γδ}$ ἄξων ὁ $\overline{ηθ}$. φανερόν οὖν ὅτι οἱ πρὸς τοῖς $\overline{η}$, $\overline{θ}$ 20 κνώδακες ἐνηρμοσμένοι εἰσὶν εἷς τινα ἐμπυελίδα ὄντα πρὸς τοῖς τοίχοις τοῦ πλινθίου. τὰ οὖν εἰρημένα ἐμπυελί-

1 μονὰς PbVd : μόνας a : μόνον AbBbLaLcLd 1-2 τε...καὶ del. Brinkmann 2 ἵνα AGT : ἵν' M 5 τι AGM : τις T 6 κέγχρον LaLcLd : κέγχρον a νάπυ a : corr. Schmidt 9 ἐνδεθέντι Schmidt dub. in app. crit. (qui etiam ἐκδεθέντι conl.) : ἐνδεθὲν M : ἐκδεθὲν AGT : ἱἐκδεθὲν Schmidt in textu : ἐκδεθέντι <ἐν> Brinkmann 11 οὐ deleui λεληθότως AGT : λελη- 12 κέγχρου AbBbLaLd^{pc}R^{2pc} : κέγχρους Ld^{ac} : κέγχρου a κινεῖ- 13 ται La^{mg} : κινεῖ AGMLa^(in textu) : [***] T 14-15 κλειθρίον...πλινθίον om. T¹ : add. T^{2mg} ὀρμὴν AMT^{2mg} : ὁ μὴν G : [***] T¹ 16 κέγχρου AbAcBb 17-18 ταπει- 19 νοῦσθαι om. G 20 $\overline{ηθ}$ AGM¹T : $\overline{εζ}$ M^{2mg} 21 ἐνηρμοσμένοι M : ἐνηρμο- 22 τοίχοις A^{cp}MT : τείχοις G 22-34.1 ἐμπυελίδα M^{2mg} : ἐμπυλῖδια AGT : ἐμπυρίδια M¹

(4) It will produce pauses of the motion however we may choose, by means of the windings of the cord and its slackenings. So, in order for the heavy counterweight not to descend in the tube too forcefully and move the case at speed, we will put something light, fine and providing resistance inside the tube, such as millet or mustard, upon which the counterweight will come to rest.

(5) We will pierce the bottom of the tube with a hole of suitable size, which will be opened and closed by a slide fastened to a cord; the end of this will be visible to us from the outside through the hole, so that, when we want the case to move, we may grab the cord and {not} unobtrusively open the slide. As the millet gently pours out into the base below, the case moves.

(6) In order for the case not to make a rush forward while the slide is being opened, the cord will have a little slack to it, so that, when a little millet has flown out, it will be pulled taut and move the case. Now I will say how the three wheels must be alternately raised and lowered.

x (1) Let there be the three stated wheels, $\overline{\alpha\beta}$, $\overline{\gamma\delta}$ and $\overline{\varepsilon\zeta}$, and $\overline{\alpha\beta}$'s and $\overline{\gamma\delta}$'s axle, $\overline{\eta\theta}$. It is thus clear that the pivots at $\overline{\eta}$ and $\overline{\theta}$ are fitted into certain sockets which are near the

δια ἔστω εἷς τινα κανόνια· τὰ δὲ κανόνια διὰ πελεκίνων καταβαινέτω ὀρθὰ εἰς τοὺς τοῦ πλινθίου τοίχους.

(2) ὁμοίως δὲ καὶ τὸ $\overline{\epsilon\zeta}$ τρόχιον ἔστω ἔν τινι κανονίῳ ὀρθῶ διὰ τινος πελεκίνου καταβιβαζομένῳ εἰς τὸν πρὸς τῷ $\overline{\epsilon\zeta}$ τοίχῳ τοῦ πλινθίου. ἔστω οὖν τὸ μὲν εἰρημένον κανόνιον 5 τὸ $\overline{\eta\theta}$. ἐκκοπὴ δὲ ἐν αὐτῷ ἢ $\overline{\kappa\lambda\mu\nu}$. ἐν δὲ ταύτῃ τρόχιον τὸ $\overline{\epsilon\zeta}$ ἄξονα ἔχον τὸν $\overline{\xi\omicron}$. πρὸς δὲ τῷ $\overline{\eta}$ ἄκρῳ τοῦ κανονίου τύλος ἐνειλείσθω ὁ $\overline{\pi}$. ἐν δὲ τῷ τοίχῳ τοῦ πλινθίου τῷ πρὸς τῷ $\overline{\epsilon\zeta}$ ἐνειλείσθωσαν δύο γόμφοι καθάπερ κανόνια, οἱ $\overline{\rho\sigma}$, $\overline{\tau\upsilon}$. ἐν δὲ τούτοις πολευέσθω κοχλίας ὁ $\overline{\varphi\chi}$, καὶ ἐμβεβη- 10 κέτω ὁ $\overline{\pi}$ τύλος εἰς τὴν τοῦ κοχλίου ἔλικα.

(3) ἐὰν οὖν τις ἐπιστρέφῃ τὸν $\overline{\varphi\chi}$ κοχλίαν, μετεωρισθήσε- ται καὶ ταπεινωθήσεται τὸ $\overline{\eta\theta}$ κανόνιον διὰ τοῦ $\overline{\pi}$ τύλου. ἵνα οὖν αὐτόματον τοῦτο γίνηται, ἐπειλείσθω περὶ τὸ ἀρ- 15 γὸν μέρος τοῦ κοχλίου σπάρτος ἐναλλάξ τὰς ἐπειλήσεις ἔχουσα καὶ χαλάσματα διαμεμηρυμένα, ἄρμοστὰ τοῖς διαστήμασιν οἷς κινεῖται τὸ πλινθίον· τὰ δὲ αὐτὰ γεγονέτω καὶ ἐπὶ τῶν λοιπῶν δύο κανονίων, ἐν οἷς εἰσιν οἱ πρὸς τοῖς $\overline{\eta}$, $\overline{\theta}$ κνώδακες.

(4) δεῖ δὲ τοὺς τρεῖς κοχλίας ἴσους τοῖς πάχεσιν εἶναι καὶ 20 τὰς ἐπειλήσεις τὰς περὶ αὐτοὺς ἀκριβῶς ἴσας καὶ τὰ χαλά- σματα ὁμοίως, ὅπως ἅμα τε ἐπαίρωνται οἱ τρεῖς τροχοὶ καὶ ἅμα καθιῶνται· οὕτω γὰρ ἀσφαλὴς καὶ εὐκίνητος ἡ τοῦ πλινθίου πορεία ἔσται.

1 <ἐνηρμοσμένα> εἷς vel <ἐμβεβηκότα> εἷς Schmidt dub. in app. crit. διὰ πελεκίνων AG M^{pcsl} T : διὰ πελεκίνω M^{ac} : διαπελεκίνω Ad Ph : διαπελέκινον codex a Baldi adhibitus 3 τροχίον a : corr. Schmidt 4 καταβιβαζομένῳ Schmidt : καταβιβαζομένου a 5 εἰρημένον AG M : εἰρημένων T 6 $\overline{\eta\theta}$ Schmidt : $\overline{\eta\theta}$ a : $\overline{\kappa\theta}$ Ad $\overline{\kappa\lambda\mu\nu}$ Vd^(secunda iteratione) : $\overline{\lambda\kappa\mu\nu}$ a τροχίον a : corr. Schmidt 7 $\overline{\eta}$ Schmidt : $\overline{\eta}$ a 8 ἐνειλείσθω a : ἐνείσθω Pa τῷ² AMT : τὸ G 12 ἐπιστρέφῃ AG : ἐπιστρέφει MT 13 $\overline{\eta\theta}$ Schmidt : $\overline{\eta\theta}$ a 14 γίνη- ται AG : γίνεται MT 14-15 ἀργὸν AG : ἀρτὸν T : αὐτὸν M^{2mg} : αὐτὸ M¹ 16 διαμεμηρυμένα Ta : διαμεμηρημένα AG T : διαμεμερισμένα M 20 πάχε- σιν AG M^{2sl} : πᾶσιν M¹ : [***] T 23 ~~καὶ~~ ἅμα T καθιῶνται a : corr. Schmidt

sides of the case. So, let the said sockets be on certain bar-frames. Let the bar-frames run vertically down the sides of the case by means of dovetails.

(2) Let the small wheel $\overline{\epsilon\zeta}$ be likewise <placed> into a certain vertical bar-frame which is made to run down by means of a dovetail to the $\overline{\epsilon\zeta}$ side of the case. So, let there be the said bar-frame, $\overline{\eta\theta}$, and a mortise in it, $\overline{\kappa\lambda\mu\nu}$. Inside this <let there be> a small wheel, $\overline{\epsilon\zeta}$, with an axle $\overline{\xi\omicron}$. At the $\overline{\eta}$ end of the bar-frame let a block $\overline{\pi}$ be screwed on. On the $\overline{\epsilon\zeta}$ side of the case let two dowels, $\overline{\rho\sigma}$ and $\overline{\tau\nu}$, be screwed on like bars. Let a screw $\overline{\varphi\chi}$ turn on these, and the block $\overline{\pi}$ engage the thread of the screw.

Fig. 10

(3) Therefore, if someone turns the screw $\overline{\varphi\chi}$, the bar-frame $\overline{\eta\theta}$ will be raised and lowered through the block $\overline{\pi}$. So, in order for this to happen automatically, let a cord be wound around the unused part of the screw, alternating windings and slack parts arranged in hanks commensurate with the distances over which the case moves. Let the same things happen in the case of the two remaining bar-frames, in which are the pivots at $\overline{\eta}$ and $\overline{\theta}$.

(4) The three screws must be equal in thickness, the windings around them precisely equal and likewise the slackenings, so that the three wheels may be raised and lowered at one and the same time. For the motion of the case will thus be safe and easy.

- XI** **(1)** Δυνατὸν δέ ἐστι καὶ ἄλλως κάμπτειν τὸ πλινθίον, οὐ μόνον ἐν ὀρθογωνίῳ παραλληλογράμμῳ, ἀλλὰ καὶ ἐν παντὶ εὐθυγράμμῳ σχήματι· ἔτι δὲ καὶ τὴν πορείαν ὀφιώδη γίνεσθαι δυνατόν ἐστι καὶ πολλῶ εὐχερέστερον τῆς προγεγραμμένης μεθόδου. 5
- (2)** ἔστω γὰρ τὸ πλινθίον, ἐν ᾧ εἰσιν οἱ τροχοί, τὸ $\overline{αβγδ}$, ἐν ᾧ διακεῖσθωσαν ἄξονες δύο οἱ $\overline{εζ}$, $\overline{ηθ}$, ὧν ὁ μὲν $\overline{ηθ}$ ἐν κνώδαξιν εὐλύτως στρεφέσθω ἔχων συμφυῇ τροχὸν τὸν $\overline{κλ}$, ὁ δὲ $\overline{εζ}$ συναραρῶς ἔστω τῷ πλινθίῳ ἀπὸ τόρνου ἰσοπαχῆς εἰργασμένος. περὶ δὲ τοῦτον περικεῖσθωσαν χοινικίδες δύο αἱ $\overline{μν}$, $\overline{ξο}$ εὐλύτως καὶ ἄρμοστῶς περὶ αὐτὸν στρεφόμεναι καὶ αὐταὶ ἀπὸ τόρνου τὴν ἐντὸς καὶ τὴν ἐκτὸς ἐπιφάνειαν εἰργασμέναι. ταῖς δὲ χοινικίσι συμφυεῖς ἔστωσαν τροχοὶ ἴσοι οἱ $\overline{πρ}$, $\overline{στ}$. 10
- (3)** ἐὰν οὖν περὶ ἑκατέραν χοινικίδα σπάρτος περιειληθεῖσα ἀποδοθῇ εἰς τὴν ἐν τῇ σύριγγι λείαν, συμβήσεται καταφερομένης τῆς λείας ἀπειλουμένων τῶν σπάρτων ἐπιστρέφεσθαι σὺν ταῖς χοινικίσι τοὺς τροχοὺς καὶ οὕτως τὸ πλινθίον ἐπ' εὐθείας πορεύεσθαι συνεπιστρεφομένον καὶ τοῦ $\overline{κλ}$ τροχοῦ. 15
- (4)** ἐὰν οὖν ἐκ τῶν $\overline{πρ}$, $\overline{στ}$ τροχῶν ὁ $\overline{πρ}$ μένη ἀκίνητος χάλασμα ἐχούσης τῆς κατ' αὐτὸν σπάρτου, ἐπιστραφήσεται ὁ $\overline{στ}$ τροχὸς καὶ συνεπιστρέψει τὸν $\overline{κλ}$, ἄχρις οὗ τὸ ἐν τῇ $\overline{μν}$ χοινικίδι χάλασμα τοῦ μηρύσματος ἐπισπάσεται ἡ λεία. εἶτα πάλιν τάσιν λαβούσης τῆς σπάρτου, ἅμα οἱ $\overline{πρ}$, $\overline{στ}$ τροχοὶ στραφήσονται, καὶ ἐνεχθήσεται τὸ πλινθίον ἐπ' εὐθείας τῆς κατὰ τὴν ἐπιστροφὴν τοῦ πλινθίου γενηθείσης. 20
- 25

3 ἔτι AG : ἔστι M : ἐστὶ T δὲ om. M 9 ἔστω ἔστω G^{ac} 12 αὐταὶ Ld : αὐταὶ M : αὐταὶ AGT 13 εἰργασμέναι AGM : εἰργασμένας T 14 ἴσοι M T : ἴσοι AG 15-16 περιειληθεῖσα G : περιειληθήσα A : περιειληφθεῖσα M T 16 καὶ συμβήσεται T 24 μηρύσματος Schmidt : μηρίσματος AGMT^{pc} : μερήσματος T^{ac} 26 στραφήσονται τροχοὶ M ἐπὶ AGT : ὑπ' M : correxi 27 τῆς AMT : τὴν G

xI (1) It is also possible to turn the case in a different way, not only in a rectangular parallelogram, but also in any rectilinear figure. Moreover, the motion can be snake-like and <this> much more easily than by the method written about before.

(2) Let there be the case in which are the wheels, $\overline{\alpha\beta\gamma\delta}$, inside of which let there be two axles, $\overline{\epsilon\zeta}$ and $\overline{\eta\theta}$; of these, let $\overline{\eta\theta}$ turn freely on pivots with a wheel attached to it, $\overline{\kappa\lambda}$, whereas let $\overline{\epsilon\zeta}$ be fitted to the case, having been worked on a lathe to an even thickness. Let two hubs, $\overline{\mu\nu}$ and $\overline{\xi\omicron}$, be set around this [the axle], turning freely and closely around it, and these with their inner and outer surfaces worked on a lathe. Let there be equal wheels attached to the hubs, $\overline{\pi\rho}$ and $\overline{\sigma\tau}$.

Figs. 11a-b

(3) So, if a cord wound around each hub, is attached to the counterweight inside the tube, it will happen that, when the counterweight descends and the cords unwind, the wheels will turn with the hubs, and thus the case will move along a straight line, and the wheel $\overline{\kappa\lambda}$ will rotate at the same time.

(4) Therefore, if $\overline{\pi\rho}$, of wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$, remains motionless because its cord has some slack to it, the wheel $\overline{\sigma\tau}$ will rotate and turn $\overline{\kappa\lambda}$ at the same time, until the counterweight takes up the slackening of the hank on the hub $\overline{\mu\nu}$. Then, when the cord becomes taut again, the wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$ will turn at the same time, and the case will be carried along a straight line resulting from its own turn.

Fig. 12

(5) δεήσει οὖν τὸ εἰρημένον χάλασμα τοσοῦτον εἶναι, ὥστε ἐπιστραφῆναι τὸ πλινθίον κατὰ τὴν εὐθείαν ἣν βουλώμεθα αὐτὸ ἐνεχθῆναι. τὰ δ' αὐτὰ ἐπινοείσθω καὶ ἐπὶ τοῦ στ' τροχοῦ. πλειόνων οὖν ἐπειλήσεων καὶ μηρυμάτων γινόμενων ἀκολουθῶς ταῖς εἰρημέναις εὐθείαις, καθ' ἃς δεῖ 5 φέρεσθαι τὸ πλινθίον, ἔσται γεγονὸς τὸ προκείμενον.

(6) δεήσει δὲ τὰ τε μήκη τῶν ἐπειλήσεων καὶ τὰ τῶν μηρυμάτων ἐξ αὐτῆς τῆς πείρας γίνεσθαι, ἀρχομένων ἡμῶν τὰς ἐπειλήσεις ποιείσθαι ἀπὸ τοῦ τόπου ἐφ' οὗ μέλλει καταλήγειν τὸ πλινθίον· ἀνάπαλιν γὰρ αὐτὸ κινοῦντες ταῖς χερσίν, 10 ὡς μέλλει πορεύεσθαι, ἐπειλήσομεν τὰς σπάρτους καὶ χάλασμα δώσομεν· οὕτω γὰρ ἀρξάμενον πορεύεσθαι τὸ πλινθίον καταλήξει δεόντως εἰς τὸν τόπον ὅθεν ἡρξάμεθα ἐπειλεῖν τὰς σπάρτους.

(7) βέλτιον δὲ καὶ τὸν κλ' τροχὸν ἐν χοινικίδι περικεῖσθαι 15 τῷ ηθ' ἄξονι, τὸν δὲ ἄξονα συμφοῇ ὁμοίως τῷ πλινθίῳ γίνεσθαι καθάπερ καὶ τὸν εζ' καὶ πάλιν περὶ τὴν χοινικίδα τοῦ κλ' τροχοῦ τὴν σπάρτον ἐπειληθεῖσαν {καὶ τὰ χαλάσματα ἔχουσιν} τῇ λείᾳ ἀποδοθῆναι, ὅπως† ὅταν βουλώμεθα κάμπτειν τὸ πλινθίον, ἓνα τῶν πρ', στ' τροχῶν 20 ἐστάναι, δηλονότι χαλάσματος ὄντος ἐν τῇ κατ' αὐτὸν σπάρτῳ τῇ περὶ τὴν χοινικίδα, τὸν δὲ κλ' τροχὸν μετὰ τοῦ λοιποῦ στρέφεσθαι τροχοῦ, ἄχρις ἂν τὸ πλινθίον τὴν δέουσιν λάβῃ ἐπιστροφὴν, εἴτα πάλιν ταθείσης τῆς τὸ χάλα-

3 δ' A M T : δὲ G 4 ἐπειλήσεων Ab Ac Bb Mb : ἐπιλήσεων A G T : ἐπιλείσεων M 7 δεήσει G T : δὲ ἡσει A : δεήση M μήκη A M T : μήκει G ἐπειλήσεων G : ἐπιλήσεων A T : ἐπειλείσεων M 9 ἐπειλήσεις A^{pc} G M : ἐπιλήσεις A^{ac} : [***] T 13-15 ἡρξάμεθα... χοινικίδι om. G 15-40.2 βέλτιον... πλινθίον del. Schmidt ἐν A M T : om. G : σὺν Schmidt dub. in app. crit. 18 ἐπειληθεῖσαν A G M : ἐπειληφθεῖσαν T 18-19 καὶ... ἔχουσιν delevi secutus Schmidt, qui suspecta habuit ista verba (sed vide ad 38.15-40.2 βέλτιον... πλινθίον) 19 ἀποδοθῆναι A G T : ἀποδεθῆναι M ὅπως A G M T^{pc} : cruces posui secutus Schmidt ('ὅπως spurium'; vide commentarium ad loc.), qui ὡς dub. coni. in app. crit. : ὁ ὅπως T^{ac} : ὅπως <συμβῆ> vel <ποιήσωμεν> Brinkmann 21 δηλονότι A G M : δῆλον ὅτι T 22 τροχὸν A M T : τροχῶν G 24 τῆς om. M T

(5) So, the said slack part will have to be such that the case turns in the straight line over which we want it to move. Let the same be imagined for the wheel $\overline{\sigma\tau}$, too. Thus, if more windings take place and hanks in accordance with the said straight lines, along which the case must be carried, what has been previously stated will happen.

(6) It will be necessary to establish both the lengths of the windings and those of the hanks by actual experiment, as we begin to make the windings from the point where the case is to stop; for when we move it by hand backwards along the path in which it is meant to travel, we will wind the cords and give them some slack. For in this way the case will start moving and necessarily stop at the place where we began to wind the cords.

(7) It is better that the wheel $\overline{\kappa\lambda}$ is also set around the axle $\overline{\eta\theta}$ on a hub, that the axle is likewise attached to the case just as $\overline{\epsilon\zeta}$ is, and again that the cord wound around the hub of the wheel $\overline{\kappa\lambda}$ {and with slack parts} is attached to the counterweight, \dagger in order that \dagger , whenever we want to turn the case, one of the wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$ comes to a stop – clearly because there is some slack in its cord around the hub – and the wheel $\overline{\kappa\lambda}$ rotates with the remaining wheel, until the case makes the necessary turn, and then, when the

Fig. 13

σμα ἐχούσης σπάρτου ἅμα κινουμένων τῶν τριῶν τροχῶν
τὴν ἐπ' εὐθείας ὁδὸν φέρεται τὸ πλινθίον.

(8) ἐπεὶ οὖν αἱ χοινικίδες αἱ τοὺς τροχοὺς ἔχουσαι περικεί-
μεναι τοῖς ἄξοσιν ἐν τῇ κινήσει δυσχερῶς ἐπιστρέφονται
διὰ <τὸ> τὸ ὅλον τοῦ πλινθίου βάρος ἐπ' αὐτὰς ἐπικεῖσθαι, 5
ἀρέσκει ἐν τοῖς αὐτομάτοις πάντα τὰ ἐγκυκλίως κινούμενα
περὶ κνώδακας στρέφεσθαι. ποιήσομεν οὖν οὕτω·

(9) γεγονέτω γὰρ τὸ πλινθίον <ἔχον> καθ' ὃν τόπον ὁ τοὺς
δύο τροχοὺς ἔχων ἄξων <ῆν> ὀρθιον διάπηγμα ἀραρός· ἐν
δὲ τούτῳ ἐμπυελίδια ἔστω ἐξ ἑκατέρου μέρους, εἰς ἃ οἱ 10
κνώδακες ἐμβιβασθήσονται. δύο δὲ ἄξονες γεγονέτωσαν
συμφυεῖς ἔχοντες τοὺς τροχοὺς, ὧν ἑκάτερος κείσθω με-
ταξὺ τοῦ εἰρημένου ὀρθίου διαπήγματος καὶ τῶν τοῦ πλιν-
θίου τοίχων ἐν κνώδαξιν, ὥστε βεβηκέναι ἐπὶ τοῦ ἐδάφους
τοὺς τροχοὺς καὶ ἕκαστον στρέφεσθαι ἐν τοῖς ἑαυτοῦ κνώ- 15
δαξιν.

(10) αἱ δὲ περὶ τοὺς ἄξονας σπάρτοι διπλαῖ ἔστωσαν, ὥστε
μεσολαβεῖν τὸν τροχὸν καὶ ἐξ ἴσου στρέφειν. γεγονέτω δὲ
καὶ ἕτερος ἄξων τούτοις ὁμοίως κινούμενος {ἐμπροσθεν

1 κινουμένων huc transposui : ante τροχῶν a 2 φέρεται cum ὅπως (38.19)
iunxit Brinkmann 3 αἱ τοὺς A^{cp} G T : αὐτοὺς M 3-4 περικείμεναι ...
ἄξοσιν del. Schmidt 5 <τὸ> Schmidt 6 ἀρέσκει A M T : ἀρέσει G
ἐγκυκλίως A^{cp} G M^{ac} (ut videtur) : ἐγκυκλῖος M^{pc} : ἐγκυ[***] T 8 γεγονέτω A^{ac}
M T : γενέσθω A^{pc} G † τὸ πλινθίον Schmidt, qui <ἐν τῷ ἐμπροσθεν μέρει>
τοῦ πλινθίου dub. conl. in app. crit. : τῷ πλινθίῳ Brinkmann <ἔχον>
Hildebrandt 8-9 καθ' ὃν... ἄξων aut delere (recepto τρόπον) aut transponere
post γεγονέτωσαν (11) dub. proposuit Schmidt in app. crit. τόπον Schmidt
dub. in app. crit. : τρόπον a 9 <ῆν> supplevi 10 ἐξ A G M^{2mg} T : ἐξ M¹
14-16 ὥστε... κνώδαξιν delenda dub. cens. Schmidt 15 ἑαυτοῦ A G T :
αὐτοῦ M 17-42.3 αἱ... τροχόν del. Schmidt, prob. Olivieri τοὺς A^{cp} M :
τοῦ G : [***] T διπλαῖ Pg (dub. in mg.) : διπλαῖ A G : διπλοὶ M : διπλάσιοι Pg (in
textu) : διπλὸν Tac : διπλῇ T^{pcsl} 18 μεσολαβεῖν Schmidt dub. in app. crit. :
μέσον λαβεῖν a 19 ἕτερος G : ἕτερος τρίτος A M T ὁμοίως A G : ὁμοιος
M : ὁμοίων T 19-42.1 ἐμπροσθεν τοῦ πλινθίου deleui secutus Schmidt
ἐμπροσθεν a : <ἐν τῷ> ὀπισθεν Schmidt dub. in app. crit.

cord with the slack is stretched taut again and the three wheels move at the same time, the case moves over the straight-line path.

(8) Thus, since the hubs holding the wheels and set around the axles move and rotate with difficulty because the whole weight of the case rests on them, it is recommended that, in the automata, anything that is moved in a circle turns around pivots. So, we will make <this> in the following way.

(9) Let there be the case <with> an upright partition fixed where the axle holding the two wheels <lay>. Let there be sockets on either side of it, in which the pivots will be inserted. Let there be two axles with the wheels attached to them; let each of these be set on pivots between the said upright partition and the sides of the case, so that the wheels rest on the ground and each <of them> turns on its own pivots.

Figs. 14a-b

(10) Let the cords around the axles be double [double-wound] so as to take the wheel in the middle [of the axle] and turn it evenly. Let there be another axle {in front of

τοῦ πλινθίου}, ὥστε πάλιν ἐπὶ τῶν τριῶν τροχῶν φέρεσθαι τὸ πλινθίον. καὶ περὶ τοῦτον ὁμοίως διπλῇ περικείμεθω σπάρτος μεσολαβοῦσα τὸν τροχόν.

(11) πάλιν οὖν τῶν σπάρτων ἐπειληθεισῶν ἐναλλάξ ὁσάκις ἐὰν βουλόμεθα καὶ τὰ χαλάσματα ἔχουσῶν ὡς ἐὰν προαιρώμεθα διαμεμηρυμένα, ὡς εἴρηται, καὶ ἡ τοῦ πλινθίου πορεία ἔσται ὡς ἐὰν προαιρώμεθα, εὐκόπως τε καὶ εὐκυλίστως διὰ τοὺς κνώδακας.

XII (1) Περὶ μὲν οὖν τῆς πορείας καὶ τῆς ἀποπορείας τοῦ πλινθίου αὐτάρκως νομίζομεν εἰρηκέναι. ἐξῆς δὲ περὶ τῶν ἐκτὸς τῆς πορείας κινήσεων ἐροῦμεν· ἔστι δὲ ἡμῖν ἡ πρώτη κίνησις περὶ τῆς τοῦ πυρὸς ἀνακαύσεως τοῦ ἐν τῷ βωμῷ.

(2) γίνεται οὖν οὕτως· ἔστω γὰρ βωμὸς ἐκ λεπίδων χαλκῶν ἢ σιδηρῶν πεποιημένος ὁ $\overline{αβγδ}$, τρύπημα ἔχων ἐν μέσῳ τῷ ἐπιπύρῳ τὸ $\overline{ε}$. ὑπὸ δὲ τοῦτο λεπίδιον ἔστω τὸ $\overline{ζη}$ παρακτὸν ὥσπερ γλωσσοκόμου πῶμα, ἐπικαλύπτον τὸ $\overline{ε}$ τρύπημα, ἐκ δὲ τούτου ἀλυσείδιον τὸ $\overline{ηθκ}$ ἀποδεδομένον περὶ ἄξονιον ἐντὸς τοῦ βωμοῦ κείμενον καὶ εὐλύτως στρεφόμενον.

(3) ἐκ δὲ τοῦ ἄξονιου ἀποδεδοσθῶ εἰς τὴν λείαν σπάρτος <***>. αὕτη δὲ μετὰ τὴν πορείαν ταθεῖσα ὑπὸ τῆς λείας

1 τριῶν AGT : ποιῶν M 2 τὸ AG : καὶ MT τοῦτον Ab Ac Ld : τούτων a διπλῇ A^{pc} GMT : διπλοῖ A^{ac} 3 μεσολαβοῦσα a : μεσοσυλλαβοῦσα Aa Bc OPb Vd 4-5 ὁσάκις M^{1cp} : corr. M^{2mg} 6 ὡς AG : ὥστε καὶ ὡς MT 8 εὐκυλίστως A^{pc} : εὐκυλίσθως A^{ac} M^{cp} : εὐκυλύτως G : εὐκυ[***] T 11 κινήσεων AGT : κινήσεως M 12 κίνησις suspectum habuit Brinkmann : μίνυσις Schmidt dub. in app. crit. 17 παρακτὸν A^{cp} G : παρ' αὐτὸν M : [***] T 18 ἀποδεδομένον AG : ἀποδεδομένον T : ἀποδεδεμένων M 19 ἐντὸς A^{cp} G : ἐν τὸ MT εὐλύτως A^{cp} GM : ἀλύτως T 21 ἐκ Schmidt dub. in app. crit. : ἐν a τοῦ ἄξονιου Schmidt dub. in app. crit. : τῷ ἄξονίῳ a, post hoc verbum lacunam dub. statuit Schmidt in app. crit. ἀποδεδόσθω AGT : ἀποδεδέσθω M 22 lacunam statui : an <χάλασμα ἔχουσα>?

the case} moving in a similar way to these, so that the case travels again on the three wheels. Let a cord be likewise laid double around this [the axle], taking the wheel in the middle.

(11) So again, when the cords are alternately wound as many times as we want with slack parts arranged in hanks however we may choose, as stated, the case will also move as we may choose, easily and smoothly because of the pivots.

xii (1) So, I believe that I have said enough about the forward and backward motion of the case. I will next talk about movements other than the journey. The first movement we have concerns the lighting of the fire on the altar.

Fig. 15

(2) It takes place as follows: let there be an altar made of bronze or iron sheets, $\overline{\alpha\beta\gamma\delta}$, with a hole in the middle of the hearth, $\overline{\varepsilon}$. Under this [the hole] let there be a plate, $\overline{\zeta\eta}$, which can be shifted aside like the lid of a chest, masking the hole $\overline{\varepsilon}$; let there be a thin chain $\overline{\eta\theta\kappa}$ attached to this [the plate] around an axle set inside the altar and turning freely.

(3) Let a cord <***> extend from the axle to the counter-weight. After the forward motion, this [the cord], having

ἐπιστρέψει τὸ ἀξόνιον καὶ παραλλάξει τὸ λεπίδιον, καὶ τῆς ἀγκύλης ἐκπεσούσης ἀπὸ τοῦ τύλου τὰ ἐξῆς ἐπιτελεσθήσεται. ὑποκείσθω δὲ τῷ ε̄ τρυπήματι λαμπτήρ ὁ μὲν τὴν φλόγα ἔχων ὑποκειμένην τῷ τρυπήματι. ἐπικείσθω δέ, ὥς προείρηται, ἐν τῷ βωμῷ ὕλη δυναμένη εὐκόπως ἀνάπτεσθαι. 5

(4) μᾶλλον δὲ τῶν ἄλλων ποιεῖ τὰ τεκτονικὰ ξύσματα. ὅταν οὖν πορευόμενον τὸ πλινθίον στῇ, τότε ἢ ἐκ τοῦ ἡθκ̄ ἄλυσειδίου σπάρτος ταθεῖσα ἐπισπάσεται τὸ ζῆ̄ λεπίδιον, ὥστε ἀνοιχθῆναι τὴν ὀπὴν καὶ τὴν φλόγα ἄνω ἐνεχθεῖσαν ἀνακαῦσαι τὸν βωμόν. τὰ δ' αὐτὰ ἐπινοείσθω καὶ ἐπὶ τοῦ ἐτέρου βωμοῦ, μόνον ὅτι τὸ τῆς σπάρτου χάλασμα μεῖζον εἶναι δεῖ τοῦ νῦν εἰρημένου, ὅπως κατὰ τὰς ἐξῆς κινήσεις ταθεῖσα ἢ σπάρτος τὴν ἐτέραν ἔξαψιν ποιήσεται. 10

XIII (1) Μετὰ δὲ τὴν θυσίαν δεῖ ἐκ μὲν τοῦ θύρσου γάλα ἀνα- 15
πτισθῆναι, ἐκ δὲ τοῦ σκύφους οἶνον.

(2) γίνεται οὖν καὶ τοῦτο οὕτως· ὑπὸ τοὺς πόδας τοῦ Διονύσου συμφυῆς γίνεται σωλὴν ἔχων τρυπήματα ἐν τῇ ἐπιφανείᾳ ἐγγὺς ἀλλήλων δύο· ἐκ δὲ τούτων σωληνάρια ἀνατείνονται εἰς τὸ ἐντὸς μέρος τοῦ Διονύσου φέροντα τὸ μὲν 20
εἰς τὸν θύρσον, τὸ δὲ εἰς τὸν σκύφον.

1-2 τῆς...τύλου aut delere aut transponere post πορείαν (42.22) dub. proposuit Schmidt in app. crit. 4 ἐπικείσθω A G T : ὑποκείσθω M 9 ἄλυσειδίου M : ἄλυσειδίου A G : ἄλυσιδίου T σπάρτος <ἐκδεθεῖσα> Schmidt dub. in app. crit. : an <ἀποδιδομένη> vel <ἀποδεδομένη> σπάρτος? 11 δ' A G : δὲ M : [***] T 13 κατὰ A G M : [***] T : μετὰ Brinkmann τὰς A^{cp} M : τὰ G : [***] T 15-16 ἀναπτισθῆναι M : ἀναπιτυσθῆναι A G T 18 συμφυῆς <τούτω> Schmidt dub. in app. crit. : an συμφυῆς <αὐτῷ>? 19 post δύο graviter interpunx. A G T et ed. princ., leviter Schmidt : non interpunx. M 19-20 ἀνατείνονται A^{accp} G T^{ac} : ἀνατείνοντα A^{psl} (τα altero addito in mg.) M T^{psl} 20 φέροντα A G : συμφέροντα M T

been pulled taut by the counterweight, will turn the axle and move the plate aside, and when the loop has fallen off the knob, what follows will be carried out. Let a grate $\overline{\mu\nu}$ be placed under the hole $\overline{\varepsilon}$, with the flame beneath the hole. Let flammable material, as has been said before, be set on the altar.

(4) Woodwork shavings work better than anything else. So, whenever the case, during its travel, comes to a stop, the cord <coming> from the thin chain $\overline{\eta\theta\kappa}$ will then become taut and draw the plate $\overline{\zeta\eta}$, so that the aperture may be opened and the flame may shoot upward and light the altar. Let the same be imagined for the other altar, except that the slack of the cord must be greater than the one just mentioned, in order for the cord, during the subsequent movements, to be pulled tight and produce the other kindling.

xiii (1) After the sacrifice, milk must be made to spurt from the thyrsus, and wine from the cup.

(2) So, this takes place as follows: a pipe is attached under Dionysus' feet, with two holes near one another on its surface; from these, small pipes extend up into the inner part of Dionysus, one leading to the thyrsus, the other to the cup.

Fig. 16 (cf. XIII.6-7)

- (3) ἔστω δὲ ἡ μὲν βάσις τοῦ Διονύσου ἡ $\overline{\alpha\beta}$, ὁ δὲ συμφυῆς
τούτῳ σωλὴν ὁ $\overline{\gamma\delta}$. τὰ δὲ ἐν αὐτῷ τρυπήματα τὰ $\overline{\epsilon}$, $\overline{\zeta}$. τὰ δὲ
ἐκ τούτων ἀνατείνοντα σωληνάρια τὰ $\overline{\zeta\eta}$, $\overline{\epsilon\theta}$, τὸ μὲν $\overline{\zeta\eta}$ εἰς
τὸν θύρσον, τὸ δὲ $\overline{\epsilon\theta}$ εἰς τὸν σκύφον. ἔστω δὲ καὶ ὁ ἐπικεί-
μενος πυρὴν τῷ ναΐσκῳ ὁ $\overline{\kappa\lambda\mu}$. ἐντὸς δὲ τούτου ἀγγεῖον
ἔστω τὸ $\overline{\nu\zeta}$ μέσον διάφραγμα ἔχον τὸ \overline{o} . καὶ ἐκ μὲν τοῦ $\overline{\nu o}$
ἀγγείου φερέτω σωλὴν ὁ $\overline{\pi\rho\sigma\tau}$ εἰς τινα ἕτερον σωλῆνα τὸν
 $\overline{\upsilon\phi}$ συνεσμηρισμένον τῷ $\overline{\gamma\delta}$ σωλῆνι, συμφυῇ δὲ ὄντα ἐκ
τῶν ὑποκάτω μερῶν τῷ καταστρώματι, ἐφ' ὃ ὁ ναΐσκος
ἐπίκειται. 5
- (4) τὸ δὲ $\overline{\tau}$ τρύπημα κείσθω κατὰ τὸ $\overline{\epsilon}$. ἐκ δὲ τοῦ $\overline{\xi o}$ ἀγ-
γείου <***> ἕτερος σωλὴν ὁ $\overline{\chi\psi\omega\varsigma}$ καὶ φέρων ὁμοίως εἰς
τὸν $\overline{\upsilon\phi}$ σωλῆνα. τὸ δὲ $\overline{\varsigma}$ τρύπημα κείσθω κατὰ τὸ $\overline{\zeta}$. οὐ-
κοῦν ἂν τις ἐν μὲν τῷ $\overline{o\kappa}$ ἀγγειδίῳ οἶνον ἐγγέη, ἐν δὲ τῷ
 $\overline{\xi o}$ γάλα, κειμένων τῶν $\overline{\epsilon}$, $\overline{\zeta}$ τρυπημάτων κατὰ τὰ $\overline{\tau}$, $\overline{\varsigma}$ ἐνε-
χθήσεται ὁ μὲν οἶνος εἰς τὸν σκύφον, τὸ δὲ γάλα εἰς τὸν
θύρσον. 10
- (5) ἴν' οὖν στέγη τὰ ὑγρά τὸν πρότερον χρόνον, κλειῖς ἔστω
ἡ $\overline{\varsigma\lambda}$ ἀποκλείουσα, ὡς εἴρηται, τὰ ὑγρά δι' ἐπιτονίου τοῦ
 $\overline{\alpha}$, περὶ ὃ ἀγκύλη σπάρτου περιβεβλήσθω χάλασμα
ἔχουσα καὶ ἀποδεδομένη εἰς τὴν λείαν, ὅπως κατὰ τὸν
δέοντα καιρὸν ταθεῖσα ἐπιστρέψῃ τὸ ἐπιτόνιον καὶ ἐνεχθῇ
τὰ ὑγρά. πάλιν δὲ ἐπιστραφέντος τοῦ Διονύσου καὶ τοῦ
ἐτέρου βωμοῦ ἀνακαυθέντος, δεῖ πάλιν ῥεῦσαι τὸν τε οἶ- 20

2 τρυπήματα AGM : τρύπηματι T 3 <φέροντα> τὸ μὲν Schmidt dub. in
app. crit. 4 ὁ om. G 11 $\overline{\tau}$ AGM^{2sl}T : τὸ M¹ 12 lacunam statuit
Schmidt, qui <καθείσθω> vel <φερέτω> (deletis verbis καὶ φέρων) dub. suppl.
in app. crit. : an <ἔστω>? καὶ φέρων a : καταφερέτω Hildebrandt : an {καὶ}
φέρων? 14 ἐν μὲν AG : ἂν μὲν M¹ : ἐν M^{2sl} : [***] T $\overline{o\kappa}$ a : [***] T : an
 $\overline{\nu o}$? τῷ² M : τὸ AGT 18 ἴν' AG : ἴνα MT 19 $\overline{\varsigma\lambda}$ Brinkmann, prob.
Schmidt in adn. crit. et Olivieri : $\overline{\varsigma\tau}$ AG^{pc}MT : $\overline{\varsigma\varsigma}$ G^{ac} : ς, T Schmidt 20 $\overline{\alpha}$
AGM : $\overline{\psi}$ T σπάρτου M : σπάρτος AGT 21 ἔχουσα καὶ ἀποδεδομένη
Schmidt ἔχουσα a : ἐχούσης Schmidt dub. in app. crit. ἀποδεδομένη AG
T : ἀποδεδομένη M : ἀποδεδομένης Schmidt dub. in app. crit. 22 an τα-
θεῖσα <ἡ σπάρτος>? ἐπιστρέψῃ AG : ἐπιστρέψει MT 24 an {πάλιν}?

(3) Let there be the base of Dionysus, $\overline{\alpha\beta}$, the pipe connected to this, $\overline{\gamma\delta}$, the holes in it, $\overline{\varepsilon}$ and $\overline{\zeta}$, and the small pipes stretching from these, $\overline{\zeta\eta}$ and $\overline{\varepsilon\theta}$, $\overline{\zeta\eta}$ to the thyrsus, $\overline{\varepsilon\theta}$ to the cup. Let there be a knob placed on top of the shrine, $\overline{\kappa\lambda\mu}$. Inside this, let there be a container, $\overline{\nu\xi}$, with a partition in the middle, \overline{o} . From the container $\overline{\nu o}$ let a pipe $\overline{\pi\rho\sigma\tau}$ lead to a certain other pipe, $\overline{\upsilon\phi}$, fitted tightly to the pipe $\overline{\gamma\delta}$ and attached from below to the covering on which the shrine rests.

(4) Let the hole $\overline{\tau}$ be set opposite $\overline{\varepsilon}$. From the container $\overline{\xi o}$ <***> another pipe, $\overline{\chi\psi\omega\varsigma}$, and likewise leading to the pipe $\overline{\upsilon\phi}$. Let the hole $\overline{\varsigma}$ be positioned opposite $\overline{\zeta}$. Then, if someone pours wine into the container $\overline{o\nu}$, and milk into $\overline{\xi o}$, the wine will be conveyed into the cup and the milk into the thyrsus, as the holes $\overline{\varepsilon}$ and $\overline{\zeta}$ lie opposite $\overline{\tau}$ and $\overline{\varsigma}$.

(5) So, to keep the liquids in at the earlier time, let there be a tap [stopcock], $\overline{\tau\lambda}$, which, as has been said, shuts the liquids off by means of a plug $\overline{\alpha}$; let a loop of cord be put around this, with some slack to it and attached to the counterweight, so that, having been pulled taut at the appropriate time, it [the cord] may turn the plug and the liquids may be conveyed. After Dionysus has rotated and the

Fig. 18

νον καὶ τὸ γάλα· στρέφεσθαι δὲ οὕτως· †ήμικυκλίου περι-
φέρεια†

(6) γεγονέτω κατὰ διάμετρον τοῖς τ , $\bar{\tau}$ τρήμασιν ἕτερα
τρήματα τὰ β , γ , καὶ ἐκ μὲν τοῦ β φερέτω σωλὴν εἰς τὸν
 $\rho\sigma$ ὁ $\beta\delta$, ἐκ δὲ τοῦ γ ἕτερος σωλὴν εἰς τὸν $\psi\omega$ ὁ $\gamma\epsilon$. ὅταν
ἄρα ἐπιστραφέντος τοῦ Διονύσου γένηται τὰ ϵ , ζ τρυπή-
ματα κατὰ τὰ β , γ , καὶ πάλιν ἀνοιχθήσεται ἡ $\overline{\zeta\lambda}$ κλείς,
καὶ ῥεύσει ὁμοίως ὅ τε οἶνος καὶ τὸ γάλα. ἀνοίγεται δὲ ἡ
κλείς ἐτέρας σπάρτου ἐπισπασαμένης τὸ ἐπιτόνιον εἰς τὰ
ἕτερα μέρη.

(7) δεῖ δὲ τοὺς $\rho\sigma$, $\psi\omega$ σωλῆνας δι' ἐνὸς κιονίσκου τῶν ἐν
τῷ ναίσκῳ κοίλου ὄντος ἐνεχθῆναι ὑπὸ τὴν βάσιν τοῦ
ναίσκου, ὅπως ἀφανεῖς ὑπάρχωσιν. ἐπιστρέφεται δὲ ὁ
Διονύσος σὺν τῇ ἐπικειμένῃ Νίκῃ τῷ πυρῇνι οὕτως· καθεί-
σθω ἄξων συμφυῆς ὢν τῇ Νίκῃ διὰ τοῦ πυρῆνος ὁ $\xi\zeta$
εὐλύτως στρεφόμενος περὶ κνώδακα τὸν ζ , καὶ περὶ αὐτὸν
περιεληθεῖσα σπάρτος διὰ τροχίλου τοῦ η ἀποδεδόσθω
εἰς τὴν βάσιν τοῦ ναίσκου καὶ διὰ τροχίλου τοῦ θ εἰς τὸ
ὑπερέχον τοῦ $\gamma\delta$ σωλῆνος.

1 στρέφεσθαι a : στρέφεται Schmidt dub. in app. crit. : an ἐπιστρέφεται? an
δὲ <τὸ ἐπιτόνιον>? οὕτως a : οὗτος Brinkmann post οὕτως graviter
interpunx. a , leviter ed. princ. : non interpunx. Schmidt 1-2 ἡμικυκλίου
περιφέρεια inter cruces posui 1-2 †περιφέρεια Schmidt, qui περιφέρειαν
dub. coni. in app. crit. 2 post περιφέρεια non interpunx. AG T et ed. princ. :
graviter interpunx. M et Schmidt 3 γεγονέτω A^{ac} M T^{ac} : γεγονέθω T^{pcsl} :
γενέσθω A^{pc} G : γεγονέτω <δὲ> vel <οὖν> Schmidt dub. in app. crit. : an
γεγονέτω <γὰρ>? 7 καὶ AG M T^{2mg} : εἰς T¹ $\overline{\zeta\lambda}$ Brinkmann, prob.
Schmidt in adn. crit. et Olivieri : $\overline{\zeta\tau}$ AG : $\overline{\zeta\psi}$ M T : ζ, T Schmidt 8 ὅ τε ὁ
οἶνος G 8-10 ἀνοίγεται...μέρη (βάρη pro μέρη recepto) del. Schmidt
ἀνοίγεται a : an κλείεται? 10 μέρη Schmidt dub. in app. crit. : βάρη A M T :
βάρη G : †βάρη Schmidt in textu 15 πυρῆνος M : πύρηνος A : πύρινος G :
[***] T 17 περιεληθεῖσα AG : περιελιφθεῖσα M : περιελιη[***] T
σπάρτος Aa^(dub. in mg.) Ab^{mg} Ac Bb Ld : om. AG M¹ T : ἀγγύλη σπάρτου M^{2mg} :
an ἄλυσις? διὰ... η AG M^{2mg} : om. M¹ : [***] T ἀποδεδόσθω AG T :
ἀποδεδέσθω M^{2mg} : om. M¹ 18 εἰς!...ναίσκου AG M^{2mg} : εἰς τὴν [***] T :
om. M¹ καὶ M^{2sl} : om. AG M¹ T $\overline{\theta}$ AG : $\overline{\theta}$ M T

other altar has lit, wine and milk must flow yet once more; to rotate in the following way; τ arc of a semicircle†

(6) Let there be other holes, β and γ , diametrically opposite to the holes τ and ς ; and from β let a pipe $\beta\delta$ lead to $\rho\sigma$, and from γ another pipe $\gamma\varepsilon$ to $\psi\omega$. Then, after Dionysus has rotated, when the holes ε and ζ face β and γ , again the tap $\xi\lambda$ will be opened, and wine and milk will likewise flow. The tap is opened when another cord has drawn the plug to the opposite side.

(7) The pipes $\rho\sigma$ and $\psi\omega$ must run through one of the shrine's columns which is hollow under the shrine's base, in order to be invisible. Dionysus rotates with the Nike placed on the knob as follows. Let an axle $\xi\zeta$ be set in such a way as to be attached to the Nike through the knob, turning freely around a pivot, ζ , and let a cord wound around it pass through a pulley η towards the base of the shrine and through a pulley θ towards the projecting part of the pipe, $\gamma\delta$.

(8) οὐκοῦν ἐὰν ἐπιστρέφῃ τις τὸν $\overline{\gamma\delta}$ σωλήνα, ἀπειλήσει τὴν περὶ τὸν $\overline{\varepsilon\zeta}$ ἄξονα σπάρτον καὶ ἅμα ἐπιστρέψει τὴν Νίκην καὶ τὸν Διόνυσον· ἐπὶ τὰ αὐτὰ δὲ ἔστω μέρη ἢ ἐπιστροφή αὐτῶν· καὶ ἴσος δὲ ἔστω κατὰ τὸ πάχος ὁ $\overline{\varepsilon\zeta}$ ἄξων τῷ $\overline{\gamma\delta}$ σωλήνι, ὅπως ἅμα ἀποκατασταθῶσιν ἢ τε Νίκη καὶ ὁ Διόνυσος μηδὲν παραλλάσσοντες κατὰ τὴν θέσιν. ἵνα γοῦν αὐτόματον τοῦτο γίνηται, ἐπειλήσθω ἑτέρα ἄλυσις περὶ τὴν ὑπεροχὴν τοῦ $\overline{\gamma\delta}$ σωλήνος καὶ διὰ τροχίλου τοῦ μ εἰς βάρος ἀποδεδόσθω τὸ μ .

(9) ὁ δὲ συγκεκοινωμένος τῷ βάρει κρίκος χειρὶ κατεχέτω καὶ σχαστηρία, καθάπερ ἐπὶ τῶν καταπελτῶν γίνεται, ὅπως τῆς σχαστηρίας ἀπολυθείσης ἀπὸ τινος σπάρτου τὸ βάρος κατενεχθὲν ἐπιστρέψῃ τὸν τε Διόνυσον καὶ τὴν Νίκην. καὶ ἡ $\overline{\eta\theta}$ δὲ σπάρτος δι' ἑτέρου κιονίσκου κρυπτέσθω, καθάπερ καὶ ἐπὶ τῶν σωλήνων εἴρηται.

XIV (1) Μετὰ δὲ τὸ σπεῖσαι πρῶτως τὸν Διόνυσον δεήσει κυμβάλων καὶ τυμπάνων κτύπον γενέσθαι. γίνεται δὲ καὶ τοῦτο οὕτως· ἐν τῇ κάτω βάσει, ἐν ᾗ εἰσι καὶ οἱ τροχοί, ἀγγεῖον τίθεται ἔχον σφαιρία μολιβᾶ συρρέοντα εἰς τὸν πυθμένα. ἐν δὲ τῷ πυθμένι τρῆμα γίνεται εὐλύτως δυνάμενον δέξασθαι τὰ σφαιρία, κλειθρίον ἔχον ἀνοιγόμενον ὑπὸ τῆς σπάρτου, ὅταν δέῃ. ὑπόκειται δὲ τῷ τρήματι τυμπάνιον ἐπικεκλιμένον, καὶ τούτῳ ἐξήφθω κυμβάλιον.

1 οὐκοῦν AGM : οὐκ οὖν T 2 $\overline{\varepsilon\zeta}$ M^{2sl} : $\overline{\varepsilon\zeta}$ AGM¹ T 3 νίκην AGM : κίνην T 6 an κατὰ τὴν <ἐξ ἀρχῆς> θέσιν? 7 γίνηται AG : γίνεται MT ἐπειλήσθω AMT : ἐπειλείσθω G ἄλυσις T : ἄλυσις AGM 9 ἀποδεδόσθω AGT : ἀποδεδέσθω M τὸ AG : τοῦ M : [***] T 10 κατεχέτω AGM : [***]τω T : κατεχέσθω vel κατέχεται Brinkmann 12 ἀπὸ a : ὑπὸ Schmidt dub. in app. crit. 14-15 κρυπτέσθω G^{pc} M : κριπτέσθω AG^{ac} T 15 καὶ om. MT 16 πρῶτως AG : πρῶτον M : [***] T 18 τοῦτο AG : τούτου MT κάτω βάσει AM : καταβάσει G : [***] T 21 ἀνοιγόμενον AGM^{2sl} : ἀποιγόμενον M¹ T : *ἀπαγόμενον ed. princ. (*ἀνοῖγ in mg.) : ἠνοιγόμενον (sic) Prou, qui etiam ἀνοιγόμενον conl. ὑπὸ AGM^{2sl} : ἀπὸ M¹ : [***] T 22 δέῃ A^{pc} G : δεήση A^{ac} : δεήσει MT τῷ τρήματι AGM : τὸ τρήματα T

(8) So, if someone turns the pipe $\overline{\gamma\delta}$, they will unwind the cord around the axle $\overline{\xi\zeta}$ and rotate the Nike and Dionysus at the same time; let their rotation occur in the same direction. Let the axle $\overline{\xi\zeta}$ be equally thick as the pipe $\overline{\gamma\delta}$, so that the Nike and Dionysus may return together without changing anything with respect to their position. Then, in order for this to happen automatically, let another chain be wound around the jut of the pipe $\overline{\gamma\delta}$ and pass through a pulley μ^{α} towards a weight μ^{β} .

(9) Let a ring, which is firmly fastened to the weight, hold it with the aid of a claw and a trigger, as happens in catapults, so that, once the trigger has been released by a certain cord, the weight may descend and turn Dionysus and the Nike. Let the cord $\overline{\eta\theta}$ be hidden by means of another column, just as has been said of the pipes.

Fig. 20

xiv (1) After Dionysus has poured a libation for the first time, there will need to be a rattle of cymbals and kettledrums. This takes place as follows: in the base below, where the wheels are too, is placed a container with small lead balls, which roll along together towards the bottom. In the bottom there is a hole that can easily receive the small balls, with a slide which is opened by the cord whenever needed. A kettledrum is placed slantwise under the hole, and a cymbal should be fastened to it.

(2) ἐκπίπτοντα οὖν τὰ σφαιρία κρούσει πρῶτον τὸ τυμπάνιον καὶ ἐκ τούτου ἀποπίπτοντα εἰς τὸ κυμβάλιον τὸν ἦχον ἀποτελέσει. δύναται δὲ μέσον διάφραγμα λαβὼν τὸ ἀγγεῖον δύο χώρας ποιῆσαι, ὥστε ἐν ἑκατέρᾳ εἶναι σφαιρία <καὶ> τὰ μὲν ἐν τῇ μιᾷ χώρᾳ τὸν πρῶτον ἦχον ἀποτελεῖν, τὰ δὲ ἐν τῇ ἑτέρᾳ τὸν ἑξῆς, κλειθρίου ὁμοίως ἀνοιχθέντος. 5

xv (1) Ἐξῆς δὲ δεῖ τὸ περιστύλιον στεφανωθῆναι τὸ ἐν τῇ βάσει.

(2) γίνεται δὲ οὕτως· νοείσθω τὸ θωράκιον τὸ ἐπικείμενον ἐν τῷ τετραστύλῳ τὸ $\overline{αβγδ}$ ἔχον ἐντὸς ἕτερον θωράκιον τὸ $\overline{εζηθ}$, ὥστε τὴν μεταξὺ τῶν δύο χώραν θωρακίων κενὴν ἐκ τοῦ κάτω μέρους ὑπάρχειν. γενηθὲν δὲ πλέγμα ἐκ στεφάνων τετραγώνων πλοκῇ οἷα ἐάν τις βούληται καὶ πρὸς τὴν ὄψιν εὐαρμόστως καὶ τοῦτο πτυγὲν ἐγκρύπτεται εἰς τὸν εἰρημένον μεταξὺ τῶν θωρακίων τόπον τὰς ἄνω ἀρχὰς ἐξημμένας ἔχον ἐκ τοῦ θωρακίου. 10 15

(3) καὶ ἵνα μὴ αὐτόματον καταφέρηται, σανίδιον ἐπίμηκες ἀρμόζον τῷ μεταξὺ τῶν θωρακίων τόπῳ καθ' ἑκάστην πλευρὰν τοῦ θωρακίου γίνεται, ὥστε ἐπιπωμάσαι τὸ πλέγμα καὶ συσχεῖν εἰς τὸ ἄνω μέρος. ἵνα δὲ μὴ αὐτόματα τὰ σανίδια ἀποπίπτῃ, ἐκ τῆς μιᾶς πλευρᾶς τῆς εἰς τὸ ἐντὸς τοῦ θωρακίου μέρος στροφωμάτια εὖλυτα λαμβάνει, ἵνα 20

5 <καὶ> Schmidt 9 δὲ <καὶ τοῦτο> Schmidt dub. in app. crit. 9-10 θωράκιον... ἕτερον add. G^{m9} 12 ὑπάρχειν A G T : ὑπάρχον M 13 †τετραγώνων Schmidt, qui τετράγωνον dub. conl. in app. crit. 14 εὐαρμόστως A^{cp} G M : [***] T : εὐαρμόστῳ Schmidt dub. in app. crit. ἐγκρύπτεται A G : ἐκρύπτεται M : ἐκκρύπτεται T 16 ἔχον a : corr. Haase 17 αὐτόματον A G : αὐτομάτην M : α[***] T 18 ἀρμόζον M^{pcsl} : ἀρμόζη A G M^{ac} T 20 αὐτόματα A M T : αὐτόματος G 21 ἀποπίπτῃ A G M : ἀποπίπτει T ἐντὸς A M T : ἐκτὸς G 22 μέρος A^{pc} G M T : μέρους A^{ac} ἐπὶ στρεπτοῦ κόρακι κατέχεται στροφωμάτια A

(2) So, as they drop, the little balls will hit the kettledrum first and, as they fall off it onto the cymbal, they will produce the sound. If the container is provided with a partition in the middle, it can form two spaces, so that there may be small balls in each one <and> those in one section may produce the first sound, those in the other the second, after the slide has likewise been opened.

xv (1) Subsequently, the peristyle on the base must be adorned with garlands.

(2) It takes place as follows: let a parapet $\overline{\alpha\beta\gamma\delta}$, which is placed on top of the four-column peristyle, be conceived as having another parapet inside, $\overline{\varepsilon\zeta\eta\theta}$, so that the space between the two parapets may be empty on the underside. Once a wreath has been made from rectangular garlands, intertwined however one wants, in a visually pleasing fashion, and once this has been folded, it is hidden in the said space between the parapets, with its upper ends fastened to the parapet.

Fig. 21a

(3) In order for it [the wreath] not to descend spontaneously, a long board is fitted to the space between the parapets along each side of the parapet so as to cover the wreath like a lid and confine it to the upper part. In order for the boards not to fall off spontaneously, they have easily moveable hinges on the inner side of the parapet, so

Fig. 21b

ὅταν <τὸ θωράκιον> ἐπιπωμασθῇ, ἐκ τοῦ ἑτέρου μέρους ἐπιστρεπτῶ κόρακι κατέχεται, ὥστε μὴ ἀνοίγεσθαι.

(4) ἐκ δὲ τοῦ ἑτέρου μέρους τοῦ κόρακος ἀγκύλη σπάρτου περιτίθεται, ἥτις ταθείσης τῆς σπάρτου καὶ τοῦ κόρακος ἐπιστραφέντος ἀποπίπτει. καὶ οὕτως τὸ πλέγμα καθίεται. 5
ἔξει δὲ τὸ πλέγμα εἰς τὰ κάτω μέρη βαρύλλια μολιβᾶ ἐκδε-
δεμένα πρὸς τὸ ταχέως καταφέρεσθαι.

XVI (1) Τὸ λοιπὸν δὲ δὴ καταλείπεται ὑποδείξαι, πῶς αἱ Βάκ-
χαι χορεύουσι κατὰ τὸν δέοντα καιρόν. γίνεται οὖν καὶ
τοῦτο οὕτως· ὁ ναῖσκος ὁ στρογγύλος, ἐν ᾧ ἐστὶν ὁ Διόνυ- 10
σος, στυλοβάτην ἔχεν στρογγύλον καὶ λεῖον κατὰ τὸ
ὕψος.

ἔστω οὖν οὗτος ὁ ἀβγδ· περὶ δὲ τοῦτον περικείμεθω
ἵτους ἢ ἐζηθκλμν ἄρμοστή τῷ στυλοβάτῃ, ὥστε εὐλύτως
περὶ αὐτὸν στρέφεσθαι. 15

(2) περὶ δὲ τὸν κρόταφον τῆς κλμν περιφερείας ἐντετορ-
νεύσθω σωλήν, ἐν ᾧ σπάρτος ἐπειληθεῖσα ἐγκεκοιμίσθω
{εἰς τὸ βάθος τοῦ σωλήνος}, ἥς ἢ μὲν μία ἀρχὴ κεκρού-
σθω δι' ἐπιούρου εἰς τὸ βάθος τοῦ σωλήνος, ὥστε μηκέτι
ἐκσπᾶσθαι. 20

(3) ἡ δὲ ἑτέρα διὰ τροχίλου ἀποδεδόςθω εἰς τὸ κάτω μέ-
ρος τοῦ θωρακίου καὶ ἐπειλήσθω εἰς ἕτερον σωλήνα ἐν-

1 <τὸ θωράκιον> supplevi 2 κατέχεται a : corr. Haase μὴ <αὐτόματα>
Schmidt dub. in app. crit. 3 μέρους A^{cp} G^{cp} M : μέτρους T 4 περιτίθε-
ται...σπάρτου om. T¹ : add. T² περιτίθεται A^{cp} G^{cp} M T² : ἐπιτίθεται Pg
5 τὸ om. M 6 μολιβᾶ AG : μολυβδᾶ M : [***] T 8 δὲ add. G^{sl} δὲ A^{pc} G
MT : δεῖ A^{ac} (ut videtur) 9 χορεύουσι AGM : χορεύου[***] T : χορεύουσιν
Schmidt dub. in app. crit. 10 ὁ² om. MT 11-12 τὸ ὕψος a : κρόταφον
Schmidt dub. in app. crit. 13 οὗτος om. MT ὁ AG : τὸ MT τοῦτον A^{pc}
MT^{pc} : τούτων A^{ac} G T^{ac} 14 στυλοβάτη AM^{ac} : στυλοβάτη M^{pcsl} : στύλω-
βατη G^{ac} : στυλωβάτη G^{pc} : στυλοβάτους T^{pcsl} : στυλωβάτους T^{ac} 16-17 ἐν-
τετορνεύσθω a : corr. Haase 18 εἰς...σωλήνος del. Schmidt ἥς AGM :
εἰς T 21 ἀποδεδόςθω AGT : ἀποδεδέσθω M 22 ἐπειλήσθω AGT :
ἐπειλείσθω M

that, when <the parapet> has been covered, they [the boards] may be held from the other side by a rotating hook, thus without opening.

(4) From the other side of the hook a loop of cord is put around, so as to fall off when the cord has been pulled taut and the hook has turned. In this way, the wreath is lowered. The wreath will have small lead weights fastened to it on the underside, so as to descend swiftly.

xvi (1) It just remains to show how the Bacchantes dance at the appropriate time. So, this takes place as follows: let the circular shrine, where Dionysus is situated, have a circular stylobate, which is also smooth over its height.

Therefore, let this be $\overline{\alpha\beta\gamma\delta}$. Let a ring $\overline{\epsilon\zeta\eta\theta\kappa\lambda\mu\nu}$ be set around it, fitting to the stylobate so as to rotate freely around it.

Figs. 22a-b

(2) Let a groove be turned on the lathe around the side of the arc $\overline{\kappa\lambda\mu\nu}$, in which a cord, having been wound, should be put {into the depth of the groove}; let one end of this be pushed into the depth of the groove by means of a peg, so as not to be pulled out any further.

Fig. 23

(3) Let the other end pass through a pulley towards the underside of the parapet and be wound into another groove

όντα ἐν τῷ τυμπάνῳ, ᾧ συμφυῆς ἔστω ἄξων εὐλύτως
στρεφόμενος. τῷ δὲ ἄξονι περιειλήσθω ἑτέρα σπάρτος καὶ
ἀποδεδόςθω εἰς τὴν λείαν. συμβήσεται οὖν ταθείσης τῆς
περὶ τὸν ἄξονα σπάρτου ἐπειλείσθαι ἐπὶ τὸ συμφυὲς αὐτῷ
τύμπανον τὴν ἐκ τῆς ἴτιος σπάρτον καὶ οὕτως χορεύειν 5
τὰς Βάκχας. ἐπεὶ οὖν δις αὐτὰς δεῖ χορεύσαι, ἔχει χάλα-
σμα διαμεμηρυμένον ἢ περὶ τὸν ἄξονα σπάρτος, ὅπως
στάσις γένηται τῶν Βακχῶν διὰ τοῦ χαλάσματος. ταθείσης
δὲ αὐτῆς πάλιν χορεύσουσιν· ἐπικείσονται γὰρ τῇ εἰρη-
μένη ἴτιι αἱ Βάκχαι. 10

XVII

(1) Ὅσαι δὲ σπάρτοι ἐκ τῆς κάτω βάσεως εἰς τὴν λείαν
ἀποδίδονται, δεῖ ταύτας ἀφανεῖς ὑπάρχειν. γίνεται οὖν καὶ
τοῦτο οὕτως·

ἔστω γὰρ τὸ στόμα τῆς σύριγγος, ἐν ᾗ ἔστιν ἡ λεία, τὸ
 $\overline{\alpha\beta\gamma\delta}$, καὶ καθείσθω διὰ τοῦ ἐν τῇ σύριγγι στόματος διά- 15
φραγμα κατὰ τὴν $\overline{\epsilon\zeta}$ εὐθείαν ἀπολαμβάνον τὸ $\overline{\delta\epsilon}$ διάστημα
ὅτι στενότατον.

(2) ἡ μὲν οὖν κέγχρος ἐμβληθήσεται εἰς τὴν $\overline{\epsilon\beta}$ χώραν, αἱ
δὲ σπάρτοι ἐκ τοῦ κάτωθεν μέρους ἀνενεχθήσονται εἰς τὴν
 $\overline{\gamma\delta\epsilon\zeta}$ χώραν καὶ ἀποδοθήσονται εἰς τὴν λείαν τὴν ἐν τῇ 20
 $\overline{\alpha\beta\zeta\epsilon}$ χώρα διὰ τροχίλου· οὕτως γὰρ ἀφανεῖς ἔσονται πᾶ-
σαι αἱ κάτωθεν ἀναφερόμεναι σπάρτοι. ἐπεὶ οὖν πολλῶν
κινήσεων γινομένων καὶ τῆς τοῦ πλινθίου πορείας πολλῆς

1 ἐν τῷ AGM : [***] T : ἐν τῷ Schmidt dub. in app. crit. εὐλύτως AGM :
εὐλύτος T 2 περιειλήσθω AG : περιειλείσθω M : περι[***] T 3 ἀποδεδό-
σθω AGT : ἀποδεδέσθω M 4 συμφυὲς AG : συμφυᾶς M : [***] T αὐτῷ
AM : αὐτὸ G : [***] T 8 στάσις AG^{bc} MT : στάσεις G^{ac} (ut videtur) χαλά-
σματος A^{pcsl} (χαλάσματος altero addito in mg.) GM^{cp} : χάσματος A^{ac} : [***]ματος T
15 καθείσθω G : καθίσθω AMT στόματος AG : σώματος M : [***]ματος
T 17 στενότατον Schmidt : στεγνότατον a 19 ἀνενεχθήσονται M : ἀνε-
χθήσονται AGT : ἐνεχθήσονται Haase 22 αἱ om. MT 23 πολλῆς a :
[***] T : μεγάλης Brinkmann

which is on the drum; a freely turning axle should be attached to this. Let another cord be wound around the axle and attached to the counterweight. So, it will happen that, when the cord around the axle has been stretched tight, the cord from the ring will be wound onto the drum that is attached to it [the axle], and the Bacchantes will thus dance. Then, since they must dance twice, the cord around the axle has a slack part forming a hank, so that there may be a standstill of the Bacchantes because of the slackening. When it [the cord] has been pulled taut, they will dance again. For the Bacchantes will be placed on the stated ring.

- xvii** (1) All the cords that extend from the base below to the counterweight must be invisible. So, this takes place as follows.

Let there be the mouth of the tube, in which is the counterweight, $\overline{\alpha\beta\gamma\delta}$, and let a partition be set through the mouth in the tube along the straight line $\overline{\epsilon\zeta}$, separating off the space $\overline{\delta\epsilon}$, which is as narrow as possible.

Figs. 24a-b

- (2) The millet will then be put inside the space $\overline{\epsilon\beta}$, and the cords from below will be brought upwards into the space $\overline{\gamma\delta\epsilon\zeta}$ and pass through a pulley towards the counterweight inside the space $\overline{\alpha\beta\zeta\epsilon}$; for all the cords that are brought up from below will thus be invisible. Therefore, since many movements take place and the journey of the case is long,

ὑπαρχούσης ἀνάγκη {μὴ} ἐξαρκεῖν τὸ τῆς σύριγγος ὕψος, δεῖ καὶ τοῦτο μηχανήσασθαι.

(3) πρὸς μὲν οὖν τὸ μήκος τῆς πορείας δύνανται οἱ περὶ τὸν ἄξονα δύο τροχοὶ αὐξανόμενοι πολὺ μήκος παρέχειν ἢ τὸ τοῦ ἄξονος πάχος ἔλασσον γινόμενον· ἅπαξ γὰρ τοῦ ἄξονος στραφέντος κινηθήσεται τὸ πλινθίον τηλικαύτην ὁδὸν ἡλικία ἐστὶν ἢ τοῦ ἐνὸς τροχοῦ περιφέρεια. διὸ εὐλόγως μείζονας αὐτοὺς δεῖ πειρᾶσθαι ποιεῖν.

- XVIII (1) Οὐ μὴν ἀλλὰ καὶ οὕτως δυνατόν ἐστι. νοείσθω γὰρ τὸ τοῦ ἄξονος πάχος τὸ $\overline{αβ}$, ἡ δὲ τοῦ συμφυοῦς αὐτῷ τροχοῦ περιφέρεια ἡ $\overline{γδ}$, καὶ ὑπερκείσθω ἕτερος ἄξων ἐν κνώδαξιν εὐλύτως στρεφόμενος, οὗ τὸ πάχος ἔστω τὸ $\overline{εζ}$. τούτῳ δὲ συμφυὲς ἔστω τύμπανον τὸ $\overline{ηθ}$. καὶ περὶ μὲν τὸν $\overline{αβ}$ ἄξονα σπάρτος περιειληθείσα ἀποδεδόσθω περὶ τὸ $\overline{ηθ}$ τύμπανον. ἐκ δὲ τοῦ $\overline{εζ}$ ἄξονος ἑτέρα σπάρτος ἐκδεθείσα καὶ ἐπειληθείσα ἀποδεδόσθω διὰ τροχίλου τοῦ $\overline{κ}$ εἰς τὴν ἐν τῇ σύριγγι λείαν τὴν $\overline{λ}$.
- (2) συμβήσεται οὖν ἅπαξ στραφέντος τοῦ $\overline{εζ}$ ἄξονος ὀλίγον μὲν μέρος τῆς σύριγγος κενοῦσθαι, τοσοῦτον ὅση ἐστὶν ἡ τοῦ $\overline{εζ}$ ἄξονος περιφέρεια, τὴν δὲ ἐκ τοῦ $\overline{αβ}$ ἄξονος σπάρτον ἅπαξ ἐπειλείσθαι <ἐπὶ> τὸ $\overline{ηθ}$ τύμπανον μείζον ὢν τοῦ $\overline{αβ}$ ἄξονος, ὥστε πλεονάκεις τὸν $\overline{αβ}$ ἄξονα στραφῆναι σὺν τῷ $\overline{γδ}$ τροχῷ καὶ διὰ τοῦτο πολὺ μήκος τῆς πορείας γίνεσθαι.

1 μὴ AG T, del. Schmidt : μὲν M^{cp} ἐξαρκεῖν AG : ἐξάρχειν M : ἐξαρχεῖν T 5-8 ἅπαξ...ποιεῖν delenda dub. cens. Schmidt, obl. Olivieri 7 post περιφέρεια lacunam suspicor 9 καὶ om. MT 10 τοῦ¹ AGM : σοῦ T αὐτῷ Schmidt : αὐτοῦ a 12 τούτῳ AG : ταύτῃ M : τούτῃ T 15 ἑτέρα AM T : ἕτερος G 18 στραφέντος Schmidt : στρέφοντος a : ἀποστραφέντος Ea Lb (ἅπαξ om.) 20 τοῦ¹ om. M 21 ἐπειλείσθαι Schmidt dub. in app. crit. : ἐπειλήσαι AG : ἐπειλείσαι T : ἀπειλείσαι M : ἀπειλήσαι Ac Ad Bb Ld <ἐπὶ> supplevi : <εἰς> Schmidt dub. in app. crit. 22 ὥστε AG : ὡς τὰ MT

the height of the tube must {not} suffice, and this, too, must be engineered.

(3) So, as for the length of the journey, either enlarging the two wheels around the axle or diminishing the axle's thickness can result in a great length; for when the axle has turned once, the case will move so long a distance as the circumference of one wheel. On this account, one must reasonably try to make them [the wheels] bigger.

xviii

(1) Over and above that, it can even be done as follows. Let the thickness of the axle be conceived [to exist], $\overline{\alpha\beta}$, and <likewise> the circumference of the wheel attached to it, $\overline{\gamma\delta}$; let another axle be placed above, turning freely on pivots, <and> whose thickness should be $\overline{\epsilon\zeta}$. Let there be a drum attached to this, $\overline{\eta\theta}$. Let a cord wound around the axle $\overline{\alpha\beta}$ pass around the drum $\overline{\eta\theta}$. Let another cord, having been fastened to the axle $\overline{\epsilon\zeta}$ and having been wound, pass through a pulley $\overline{\kappa}$ towards the counterweight inside the tube, λ .

Figs. 25a-b

(2) So, it will happen that, when the axle $\overline{\epsilon\zeta}$ has turned once, a small part of the tube will be emptied in a way commensurate with the circumference of the axle $\overline{\epsilon\zeta}$, and the cord from the axle $\overline{\alpha\beta}$ will be wound once <onto> the drum $\overline{\eta\theta}$, which is bigger than the axle $\overline{\alpha\beta}$, so that the axle $\overline{\alpha\beta}$ may turn several times with the wheel $\overline{\gamma\delta}$, and thus a great length of the journey may be attained.

(3) εἰδέναι μέντοι χρή, ὅτι μείζονος λείας προσδεῖται διὰ τὸ τοὺς μείζονας κύκλους ὑπὸ τῶν ἐλασσόνων κινεῖσθαι· ταῦτα γὰρ διὰ τῶν μοχλίων δὴ ἔστι. καὶ τὰς ἄλλας δὲ τὰς ἔξωθεν τῆς πορείας κινήσεις δυνατόν ἐστι μεγάλας οὔσας διὰ μικρῶν διαστημάτων ἐπιτελεῖσθαι·

5

(4) ἐὰν γὰρ ἡ κινούσα τὸ ὄργανον τοῦ Διονύσου σπάρτος περὶ μείζονας κύκλους ἀποδιδῶται, ἡ δὲ εἰς τὴν λείαν περὶ ἐλάσσονας ἄξονας καὶ συμφυεῖς ὄντας τῷ μείζονι, καθάπερ καὶ ἐπὶ τῆς πορείας ὑπεδείξαμεν.

XIX (1) Δύναται δὲ καὶ ἄλλως ἢ τε ἐπιπορεία καὶ ἡ ἀποπορεία γίνεσθαι καὶ αἱ ἔξωθεν <τῆς πορείας> κινήσεις.

10

ἔστω γὰρ τὸ τῆς σύριγγος στόμα τὸ $\overline{αβγδ}$ διαπεφραγμένον δυσὶ διαφράγμασι δι' ὅλου τοῦ ὕψους τῆς σύριγγος τοῖς κατὰ τὰς $\overline{εζ}$, $\overline{ηθ}$ εὐθείας, ὥστε διὰ τοῦ μεταξὺ τόπου τῶν διαφραγμάτων τὰς κάτω σπάρτους ἀναφέρεσθαι καὶ ἀποδίδοσθαι εἰς τὰς λείας.

15

(2) ἡ μὲν οὖν ἐν τῇ $\overline{αβεζ}$ σύριγγι λεία τὴν τε ἐπιπορείαν ποιήσεται καὶ τὴν ἀποπορείαν, ἡ δὲ ἐν τῇ $\overline{ηθγδ}$ τὰς ἄλλας κινήσεις οὕτως· ἔστω γὰρ τὸ μὲν ἐν τῷ πυθμένι τῆς $\overline{αβεζ}$ σύριγγος τρήμα, δι' οὗ ἡ κέγχρος ἐκρέει, τὸ $\overline{κ}$, τὸ δὲ ἐν τῇ

20

1 προσδεῖται **a** : προσδεῖ Schmidt dub. in app. crit. 2 κινεῖσθαι, <ὅταν περὶ τὸ αὐτὸ κέντρον κυλίωνται> Schmidt dub. in app. crit. 3 μοχλίων δὴ ἔστι **A** **G** : μοκλίων [***] **T** : κοχλίων δὲ ἔστι **M** : κοχλίων vac. δὴ ἔστι (vel ἔστι) **Ab** ^(de ac) **Ac** : κοχλίων vac. δὲ ἔστι **Bb**, post κοχλίων graviter interpungens : μοχλικῶν δὴλά ἔστι Brinkmann δὴ post γὰρ transp. dub. Schmidt in app. crit. 6-9 ἐὰν... ὑπεδείξαμεν delenda dub. cens. Schmidt, prob. Brinkmann et Olivieri γὰρ **A^{op} G** : om. **M** : [***] **T** : delendum dub. cens. Schmidt (sed vide notam praecedentem) ἡ om. **MT** τοῦ διονύσου del. Brinkmann 7 ἀποδίδεται **AGT** : ἀποδίδοται **M** : corr. Schmidt 8 τῷ μείζονι **a** : τῷ μείζονι <κύκλῳ> Schmidt dub. in app. crit. : τοῖς μείζοσι Schmidt in adn. crit. 10-62.20 totum hoc caput interpolatum cens. Olivieri ἡ om. **M** 11 <τῆς πορείας> Schmidt 12-13 διαπεφραγμένον **AG** : διαπεφραγμένων **MT** 14 τοῖς **AT** : τῆς **G** : om. **M** 15 κάτω **AGM** : [***] **T** : ἀν κάτωθεν? 17 τε **AG** : δὲ **MT** 18 τὴν om. **M** 20 ἐκρέει **AGM T^{ac}** : ἐκρέη **T^{pc}**

(3) However, one must know that a bigger counterweight is needed as bigger circles are moved by smaller ones; for these things take place by means of levers. Big as they are, the movements other than the journey can be completed through small radii.

(4) For <this happens> if the cord that moves the instrument of Dionysus passes around bigger circles, and the one going towards the counterweight passes around smaller axles, which are also attached to the bigger one, just as I have shown for the journey.

XIX (1) It is also possible for both the forward and backward motion and the movements other than <the journey> to take place in a different way.

Let there be the mouth of the tube, $\overline{\alpha\beta\gamma\delta}$, divided by two partitions through the entire height of the tube along the straight lines $\overline{\varepsilon\zeta}$ and $\overline{\eta\theta}$, so that the cords below may be brought up through the space between the partitions and attached to the counterweights.

Figs. 26a-b

(2) So, the counterweight in the tube $\overline{\alpha\beta\gamma\delta}$ will produce both forward and backward motion, and the counterweight in $\overline{\eta\theta\gamma\delta}$ <will produce> the other movements as follows; for let there be a hole in the bottom of the tube $\overline{\alpha\beta\gamma\delta}$,

Fig. 27

ἡθγδ̄ τὸ λ̄. ἑκατέρω δὲ κλειθρίον γεγονένω δυνάμενον
εὐκόπως παράγεσθαι.

(3) ὅταν οὖν μέλλη πορεύεσθαι τὸ πλινθίον, παράξομεν τὸ
τοῦ κ̄ τρυπήματος κλειθρίον, ὥστε ἀνοιχθῆναι. καὶ ἵνα
<μῆ> εὐθέως ὀρμὴν λαβὼν τὸ πλινθίον κινηθῇ, ἔξει ἡ 5
σπάρτος ἢ ἐκ τῶν {ὑπὲρ} τροχῶν ἀποδιδομένη εἰς τὴν
λείαν χαλασμάτιον. καὶ δῆλον ὅτι χρόνος τις ἔσται ἀπο-
στάντων ἡμῶν πρὸ τοῦ κινηθῆναι τὸ πλινθίον, τοσοῦτος
ὅσον ἦν τὸ τῆς σπάρτου χάλασμα.

(4) ὅταν δὲ δέῃ στήναι τὸ πλινθίον καὶ τὰς ἄλλας ἐπιτελέ- 10
σαι κινήσεις, ἔτι ἐπιπορευομένου αὐτοῦ σπάρτος τις ἐπι-
σπάσεται τὸ πρὸς τῷ λ̄ κλειθρίον καὶ ἀνοίξει αὐτό. καὶ
πάλιν, ἵνα μὴ πορευομένου ἑτέρα γένηται κίνησις, ἔξει
χάλασμα καὶ ἢ ἐκ τῆς ἑτέρας λείας ἐκδεδεμένη σπάρτος,
ἥτις ταθεῖσα ἐπισπάσεται καὶ τὸ πρὸς τῷ κ̄ κλειθρίον. 15

(5) καὶ οὕτως στήσεται τὸ πλινθίον, αἱ δὲ ἄλλαι ἐπιτελε-
σθήσονται κινήσεις. ὅταν οὖν πάλιν δέῃ ἀποπορεύεσθαι
τὸ πλινθίον, ἑτέρα σπάρτος ἐπισπάσεται τὸ πρὸς τῷ κ̄
κλειθρίον καὶ ἀνοίξει αὐτό. καὶ οὕτως τὴν ἀποπορείαν
ποιήσεται. 20

1 λ̄ (vel λ') A G T : δ̄ M 3 παράξομεν a F (in textu) : προσάξομεν F (dub. in mg.)
5 <μῆ> Schmidt 6 ὑπὲρ τροχῶν G, ὑπὲρ del. Schmidt : ὑπερτροχῶν M :
ὑπερτροχῶν A : [***]όχων T 10-11 ἐπιτελέσαι A G M^{pc} : ἀποτελέσαι M^{ac} :
[***] T 11 ἔτι A G M : ἐστι T ἐπιπορευομένου A G : πορευομένου M :
[***] T 15 an καὶ <κλείσει>? 18 τὸ² A M T : τῷ G

through which the millet flows out, $\bar{\kappa}$, and a hole in $\overline{\eta\theta\gamma\delta}$, $\bar{\lambda}$. Let each have a slide which can be easily shifted.

(3) Then, when the case is about to move, we will shift the slide of the hole $\bar{\kappa}$, so that it may be opened. In order for the case <not> to make a sudden rush forward and move, the cord going from the {over} wheels to the counterweight will have a slack to it. It is clear that, once we have stood away before the case moves, there will be an interval as long as the slack of the cord.

(4) When the case must come to a halt and complete the other movements, a certain cord will pull the slide at $\bar{\lambda}$ and open it while the case is still travelling. Again, in order that no other movement may occur while it [the case] is moving, the cord bound to the other counterweight – which, when stretched tight, will also pull the slide at $\bar{\kappa}$ – will have some slack too.

(5) The case will thus stop, and the other movements will be completed. So, when the case must come back again, another cord will pull the slide at $\bar{\kappa}$ and open it. In this way, it [the case] will effect its backward motion.

ΠΕΡΙ ΣΤΑΤΩΝ ΑΥΤΟΜΑΤΩΝ

xx (1) Ὅσα μὲν οὖν ἔδει περὶ τῶν ὑπαγόντων αὐτομάτων
πραγματευθῆναι, νομίζομεν ἱκανῶς ἀνεστράφθαι ἐν τοῖς
προγεγραμμένοις· καὶ γὰρ εὐκόπως καὶ ἀκινδύνως καὶ
ξένως παρὰ τὰ πρὸ ἡμῶν ἀναγεγραμμένα κατακεχωρίκα- 5
μεν, ὥς ἔστι δῆλον τοῖς πεπειραμένοις τῶν πρότερον ἀνα-
γεγραμμένων. περὶ δὲ τῶν στατῶν αὐτομάτων βουλόμεθα
γράφειν καινότερόν τι, καὶ βέλτιον τῶν πρὸ ἡμῶν ἅμα καὶ
πρὸς διδασκαλίαν <μᾶλλον> ἀρμόζον οὐδὲν εὕρομεν τῶν
ὑπὸ Φίλωνος τοῦ Βυζαντίου ἀναγεγραμμένων. 10

(2) ἔστι δὲ <ὁ> μῦθος καὶ ἡ διάθεσις τῶν περὶ τὸν Ναύ-
πλιον, ἐν ᾗ πολλαί τε καὶ ποικίλαι διαθέσεις ὑπάρχουσι
καὶ οὐ φαύλως οἰκονομούμεναι πλὴν τῆς μηχανῆς τῆς περὶ
τὴν Ἀθηνᾶν· ἐργωδέστερον γὰρ πῶς τὴν κατασκευὴν ἐποι-
ήσατο· δυνατόν γὰρ ἦν χωρὶς μηχανῆς φανῆναι αὐτὴν ὑπὸ 15
τὸν πίνακα καὶ μετὰ ταῦτα πάλιν ἀφανῆ γενέσθαι· τὸ γὰρ
ζῳδῖον αὐτῆς δυνατόν ἐστι περὶ τοὺς πόδας ἐν γιγλῶμῳ
κινούμενον τὸν μὲν πρῶτον χρόνον κατακεκλιμένον εἶναι,
ὥστε μὴ φαίνεσθαι, ἔπειτα δὲ ὥσπερ <ἐγερθὲν> ὑπὸ σπάρ-

1 περὶ στατῶν αὐτομάτων AG (hunc titulum ex Philoni Byzantino promptum
esse suspicor, nisi hoc loco interpolatum fuerit; vide Introductionem, pp. lxx-
lxxi) : περὶ στατῶν ἄ[...] T : om. M 3 ἀνεστράφθαι AG : ἀνεστράφ[***] T :
ἀναγεγράφθαι M 5 ξένως A^{CP} GM : καινῶς Diels et Weil dub. 5-6 κατα-
κεχωρίκαμεν R. Schöne : κατακεχωρήκαμεν a : μετακεχειρίκαμεν Weil dub.
6 ἔστι a : ἔσται H. Schöne τοῖς πεπειραμένοις <τῶν τε ὑφ' ἡμῶν καὶ τῶν
ὑπὸ> H. Schöne 7 <καὶ> περὶ Schmidt dub. in app. crit. βουλόμεθα a :
βουλόμενοι Haase 8 γράφειν AG : ἐπιγράφειν MT : ἔτι γράφειν Prou
ante καινότερόν leviter interpunx. AG et Haase, graviter Prou τι AG M :
[***] T : δὲ vel τε Prou ante καὶ¹ leviter interpunxi, graviter Schmidt : non
interpunx. AG M, Haase et Prou 9 <μᾶλλον> Susemihl dub. et Diels
εὕρομεν A^{CP} G : εὕρωμεν M^{CP} : [***] T 10 καὶ ἀναγεγραμμένων M
11 <ὁ> Schmidt dub. in app. crit. τῶν AG : καὶ MT : aut delere aut in αὐτῷ
(i.e. Φίλωνι) mutare voluit Brinkmann 14 ἐργωδέστερον A^{CP} GM : ἐργωδέ-
στερόν Pe : ἐργωδέστρον T : ἐργωδεστέραν Prou 15 ὑπὸ MT : ὑπὲρ AG
17 πόδας A^{ac} GM : πόδους A^{PC} T γιγλῶμῳ A : γιγλύμῳ GM^{PCSI} : γιγλόμῳ
M^{ac} : [***]ω T 19 ὥσπερ suspectum habuit Schmidt, qui tamen post hoc
verbum lacunam suspicatus est <ἐγερθὲν> supplevi

ON STATIONARY AUTOMATA

xx (1) So, I consider that I have adequately covered in what has been written before whatever needed to be discussed about the mobile automata; for I have recorded methods that are feasible, riskless and unusual compared to those described before us, as is clear to anyone who has tested the previously described methods. As for the stationary automata, I want to write something rather original, and I have found, of my forebears' writings, none better and at the same time <more> apt for teaching purposes than those of Philo of Byzantium.

(2) The events about Nauplius constitute <the> story and the arrangement. In it there are many and diverse configurations, which are not poorly handled except for Athena's machine. <Philo>, in fact, made its construction somewhat too laboriously. For it was possible for her to appear inside the box without a machine and then disappear again; for her figure can be moved on a hinge by its feet and initially laid down, so as not to be visible, and then, as though

του τινὸς ἐπισπασαμένης ὀρθὸν φανῆναι καὶ πάλιν ὑπὸ
ἐτέρας κατακλιθῆναι.

(3) ἔτι δὲ καὶ ὑποσχόμενος πρὸς τούτῳ κεραυνὸν πεσεῖν
ἐπὶ τὸ τοῦ Αἴαντος ζώδιον καὶ βροντῆς ἦχον γενέσθαι οὐ
κατεχώρισε· πολλοῖς γὰρ συντάγμασι περιτυχόντες οὐχ
εὔρομεν τοῦτο ἀναγεγραμμένον. καὶ ἴσως δόξει τις ἡμᾶς
κατατρέχοντας τοῦ Φίλωνος διαβάλλειν αὐτὸν ὥς μὴ δε-
δυνημένον τὴν ὑπόσχεσιν ἀπαρτίσαι, ἀλλ' οὐχ οὕτως ἔχει.

(4) πολλῶν δὲ οὐσῶν τῶν ἐν τῇ διαθέσει ὑποσχέσεων,
ἴσως ἔλαθεν αὐτὸν ἀναγράφοντα αὕτη. δυνατὸν γάρ ἐστιν
ἀγγεῖόν τι ἐν αὐτῷ σφαιρία ἔχον μολιβᾶ καὶ ἔχον τετρυπη-
μένον τὸν πυθμένα ἀποσχάζεσθαι κατὰ τὸν δέοντα και-
ρόν, τὰ δὲ σφαιρία ἐμπίπτοντα διφθέρα ἐξηπλωμένη, ξηρᾶ
καὶ πυκνῇ τὸν ἦχον τῆς βροντῆς ἀποδιδόναι· καὶ γὰρ ἐν
τοῖς θεάτροις ὅταν δέῃ τὸν ὅμοιον ἦχον γενέσθαι, ἀγγεῖα
ἀποσχάζεται βάρη ἔχοντα, ἵνα φερόμενα ἐπὶ διφθέρας, ὥς
εἴρηται, ξηρᾶς καὶ περιτεταμένης {τῆς βύρσης} καθάπερ
ἐν τυμπάνοις τὸν ἦχον ἀποτελῇ.

(5) περὶ δὲ τῶν λοιπῶν τῶν ἐν τῇ διαθέσει τοῦ Ναυπλίου
κατὰ μέρος γινομένων εὐαρεστούμεθα ὥς ἐν τάξει καὶ
εὐμεθόδως ὑπ' αὐτοῦ ἀναγεγραμμένων. διὸ δὴ οὐ παρητη-
σάμεθα τὰ ὑπ' αὐτοῦ περὶ ὧν εἵπομεν γεγραμμένα· οὕτως
γὰρ νομίζομεν τοὺς ἐντυγχάνοντας τῆς μεγίστης ὠφελείας

2 κατακλιθῆναι A^{cp} M : κατὰ κλιθῆναι G : [***]ῆναι T 5 κατεχώρισε Ac^{2mg}
Ld^{mg} : κατεχώρησε a Ac¹ Ld (in textu) 6 post εὔρομεν T iam non legitur; vide
Introductionem, p. xlii post ἀναγεγραμμένον non interpunx. Weil καὶ
ἴσως Haase : καθὼς a, post hoc verbum lacunam dub. statuit Schmidt in app.
crit. : κακῶς Prou : καθαρῶς Weil, postea graviter interpungens δόξει a :
λέξει Prou 7 κατατρέχοντας A^{cp} G : κατατρέχοντες MT 10 ἴσως A^{cp} G :
ἴσος M αὕτη Weil et R. Schöne : αὐτὴν (vel -ήν) a 11 αὐτῷ Prou : αὐτῷ
a 16 ἀποσχάζεται Prou : ἀποσχάζονται A G M 17 περιτεταμένης A G M^{2sl}
: ἐπιτεταμένης M^{1cp} τῆς βύρσης del. R. Schöne, ut glossema ad διφθέρας
(16)? 18 ἀποτελῇ A G : ἀποτελεῖ M 19 τῶν¹ A^{cp} M : τὸν G 21 οὐ om.
M

<roused> by the pull of a certain cord, it can appear upright and be laid down again by another <cord>.

(3) Moreover, although he promised, in addition to this, to make a bolt of lightning fall on the figurine of Ajax and to produce the sound of thunder, he did not record it; for although I have come across many of his books, I did not find this recorded. Perhaps one will think that in running Philo down I am criticising him for being unable to fulfil the promise, but it is not so.

(4) Since his promises in the arrangement are many, perhaps he forgot to write this one out. For a container with small lead balls inside and with a hole in the bottom can be opened at the appropriate time, and the small balls can make the sound of thunder as they fall on a piece of dry and dense leather which has been spread out. For in theatres, too, whenever it is necessary to produce a similar sound, containers holding weights are opened, so that, as they fall on a piece of leather, which is – as stated – dry and tightly stretched {the hide}, the weights may generate the sound, just like in kettledrums.

(5) As for the other things which take place one by one in the Nauplius arrangement, I am very happy with the orderly and well-thought-out way they have been set down by him [Philo]. For this reason, then, I have not rejected his writings about the things I said; for in this way I be-

τυγχάνειν, ὅταν τὰ μὲν καλῶς ὑπὸ τῶν ἀρχαίων εἰρημένα παρατιθῇται αὐτοῖς, τὰ δὲ παραθεωρηθέντα ἢ διορθώσεως τυχόντα καταχωρίζεται. περὶ τῆς τῶν πινακίων οὖν κατασκευῆς νῦν ἀρξώμεθα λέγειν.

- XXI** **(1)** Ἔστι μὲν οὖν παρὰ πολὺ τῶν ὑπαγόντων ἡ ποίησις 5
ἀσφαλεστέρα τε καὶ ἀκινδυνότερα καὶ τὴν ἐπίδειξιν οὐκ
ἀπίθανον ἔχουσα. τὸ δὲ πρόβλημά ἐστι τοιοῦτον, ὥστε
πίνακος ἐπιτεθέντος ἐπὶ τι κιόνιον ξύλινον ἀνοιχθῆναί τε
αὐτόματον καὶ τὰ ἐν αὐτῷ ἐξωγραφημένα φαίνεσθαι κι-
νούμενα πρὸς λόγον τῆς ὑποκειμένης διαθέσεως, καὶ πάλιν 10
κλεισθέντος αὐτομάτου διαγενέσθαι ὀλίγον παντελῶς
χρόνον καὶ ἀνοιχθέντος φαίνεσθαι ἄλλα τὰ ἐν αὐτῷ γε-
γραμμένα καὶ εἰς τὸ δυνατόν πάλιν ταῦτα ἢ τινα αὐτῶν
κινεῖσθαι καὶ τοῦτο πάλιν πλεονάκις γενέσθαι
- (2)** καὶ ἐκτὸς τῶν πινάκων ἡ μηχανὰς αἰρομένας φαίνε- 15
σθαι καὶ περιανομένας ἢ ἄλλας τινὰς κινήσεις. ἡ μὲν οὖν
ὑπόθεσις τοιαύτη· χαριέστατος δὲ τῶν μεταχειριζομένων ὁ
γλαφυρωτάτην διάθεσιν ἐπινοῶν. ὥστε προθησόμεθα μίαν
τῶν διαθέσεων, ἣν μάλιστα κρίνομεν, καὶ μετὰ <ταῦτα>

1 τὰ om. MT εἰρημένα A^{CP} G M^{CP} : εὐρημένα Prou 2 παρατιθῇται Schmidt : παρατίθεται A G^{PCSI} : παρατίθεται G^{ac} M aut {ἢ} aut ἢ <παραλειφθέντα> (vel sim.) Brinkmann : ἢ <δυσχερῶς ῥηθέντα> vel <διαμαρτηθέντα> Schmidt dub. in app. crit. 5 ἡ <***> ποίησις Schmidt, qui <τῶν στατῶν> dub. suppl. in app. crit. : ἡ ποίησις <τῶν στατῶν> Prou 7 ἀπίθανον G M : ἀπείθανον A T 8 ἀνοιχθῆναί ναί τε G τε <αὐτὸν> αὐτόματον Schmidt dub. in app. crit. 9 ἐξωγραφημένα A^{CP} G : ἔξω γραφημένα M^{CP} 10-11 πάλιν ante ἀνοιχθέντος (12) transp. dub. Schmidt in app. crit. : an referendum ad φαίνεσθαι (12)? 12 ἄλλα τὰ a : ἄλλὰ τὰ Pf, rec. Prou : ἄλλα τινὰ vel ἄλλα τε Brinkmann : τὰ ἄλλα Schmidt dub. in app. crit. : ἄλλ' ἄττα Diels : an ἄλλα {τὰ}? 13 ταῦτα Weil : τὰ αὐτὰ a : <πάντα> ταῦτα Schmidt dub. in app. crit. 15 ἡ del. Weil αἰρομένας R. Schöne : ἐρρωμένας a, rec. Weil 15-16 φαίνεσθαι καὶ A G M : φέρεσθαι ἢ Weil 16 τινὰς <κινουμένας> Weil 17 τῶν om. G 18 προθησόμεθα A^{CP} G^{CP} M : παραθησόμεθα Brinkmann : an προθήσομεν? 19 μάλιστα <ἀρμόζουσιν> Schmidt dub. in app. crit. κρίνομεν A^{CP} G M : ἐγκρίνομεν H. Schöne <ταῦτα> Weil

lieve that those who come across <my treatise> obtain the greatest benefit, when things well said by the ancients are laid before them, and those which have been overlooked or have been corrected are also placed on record. So, I will now begin to talk about the construction of the boxes.

xxi **(1)** Therefore, the making [of stationary automata] is much safer and freer from danger than that of mobile automata, as well as involving a performance which is not implausible. The issue is such that, once a box has been set on a little wooden pillar, it opens by itself and the painted figures inside it are shown moving in accordance with the current arrangement; and again, after it has closed by itself, a very short time elapses and, once opened, other figures which are painted in it appear, and as far as possible these, or some of them, move once more – and this repeats itself several times;

(2) outside the boxes either machines are shown being raised and turned around or some other movements. So, such is the proposition; but the most refined of the practitioners is the one who devises the neatest arrangement. As a result, of the arrangements I will propose one which I

τὴν κατασκευὴν ἐμφανιοῦμεν· ἀρκέσει γὰρ περὶ ἑνὸς πί-
νακος <***>· διὰ γὰρ τῶν αὐτῶν πάλιν τὰ αὐτὰ οἰκονο-
μεῖται, καθάπερ καὶ ἐπὶ τῶν ὑπαγόντων ἀπεδείξαμεν.

- XXII** **(1)** Οἱ μὲν οὖν ἀρχαῖοι κέχρηται ἀπλῇ τινι διαθέσει· ἀνοι-
χθέντος γὰρ τοῦ πίνακος, ἐφαίνετο ἐν αὐτῷ πρόσωπον 5
γεγραμμένον. τοῦτο δὲ τοὺς ὀφθαλμοὺς ἐκίνει καμμύον τε
καὶ ἀναβλέπον πολλάκις. ὅταν δὲ πάλιν κλεισθεὶς ἀνοιχθῇ
ὁ πίναξ, τὸ μὲν πρόσωπον οὐκέτι ἑωρᾶτο, ζῳδια δὲ γε-
γραμμένα ἔς τινα μῦθον διεσκευασμένα.
- (2)** καὶ πάλιν ὅταν κλεισθεὶς ἀνοιχθῇ, διάθεσις ἄλλη ἐφαί- 10
νετο ζῳδίων συναναπληροῦσα τοὺς ὑποκειμένους μύθους
τοὺς ἐξῆς, ὥστε τρεῖς μόνον κινήσεις διαφόρους ἐπὶ τοῦ
πίνακος γίνεσθαι, μίαν μὲν τῶν θυρῶν, ἄλλην δὲ τῶν ὁμ-
μάτων, τὴν τρίτην <δὲ> τῶν ἐπικαλυπτόντων. οἱ δὲ καθ’
ἡμᾶς μύθους τε ἐμβεβλήκασιν εἰς τοὺς πίνακας ἀστείους 15
καὶ κινήσεσι κέχρηται πολλαῖς καὶ ἀνομοίαις.
- (3)** καθὰ δὲ προεθέμην, ἐρῶ περὶ ἑνὸς πίνακος τοῦ δο-
κοῦντός μοι κρεῖττονος. μῦθος μὲν ἦν τεταγμένος ἐν αὐτῷ
ὁ κατὰ τὸν Ναύπλιον. τὰ δὲ κατὰ μέρος εἶχεν οὕτως· ἀνοι-
χθέντος ἐν ἀρχῇ τοῦ πίνακος ἐφαίνετο ζῳδια γεγραμμένα 20
δώδεκα· ταῦτα δὲ ἦν εἰς τρεῖς στίχους διηρημένα· ἦσαν δὲ
οὗτοι πεποιημένοι τῶν Δαναῶν τινες ἐπισκευάζοντες τὰς
ναῦς καὶ γινόμενοι περὶ καθολκὴν.

1 περὶ M : παρὰ A G : παρ’ T 2 lacunam statuit Schmidt secutus H. Schöne, qui <διασαφεῖν τοῦ ***> suppl. : <λέγειν τοῦ δοκοῦντος κρεῖττονος> Schmidt dub. in app. crit. : nullam lacunam agnovit R. Schöne : an <λέγειν τοῦ δοκοῦντος μοι κρεῖττονος>? 3 καὶ om. M 5 ἐφαίνετο A G : ἐμφαίνεται M 8 ἑωρᾶται M^{ac} : corr. M^{sl} 10-11 ἐφαίνετο M : ἐφαίνητο A G T 12 τοὺς Ea Lb : τοῖς a 13 θυρῶν A^{cp} G : θυρῶν T : θύρῶν M^{cp} 14 an τὴν delendum? <δὲ> τρίτην Schmidt dub. in app. crit. <δὲ> Prou 15 ἡμᾶς A G : ὑμᾶς M 16 ἀνομοίαις M^{ac} : corr. M^{sl} 23 καθολκὴν Ab Ac : καθολικὴν a

particularly rare, and after <this> I will explain its construction. It will be enough <***> about only one box; for again the same things are handled by the same methods, just as I have proved for the mobile automata.

xxii **(1)** So, the ancients employed a certain simple arrangement: when the box opened, a painted face appeared in it. This moved its eyes, closing and opening them several times. When the box closed and opened again, the face was no longer seen, but painted figurines <were seen>, prepared for the sake of some story.

(2) And again, when it [the box] closed and opened, another arrangement of figurines appeared, completing the current stories one after another, so that only three different movements would take place in the box, one of the doors, another of the eyes, and the third of the coverings. On the other hand, our contemporaries have inserted stylish stories inside the boxes and have made use of many and disparate movements.

(3) As I proposed, I will talk about one box which seems superior to me. The story set in it was the one about Nauplius. The individual scenes went as follows. At the outset, when the box opened, twelve painted figurines appeared: these were divided into three rows; they were made to represent some of the Greeks refitting their ships and busy launching them.

(4) ἐκινεῖτο δὲ ταῦτα τὰ ζῳδια τὰ μὲν πρίζοντα, τὰ δὲ πε-
λέκεσιν ἐργαζόμενα, τὰ δὲ σφύραις, τὰ δὲ ἀρίσι καὶ τρυ-
πάνοις χρώμενα <καὶ> ψόφον ἐποίουν πολύν, καθάπερ ἐπὶ
τῆς ἀληθείας {γίνοιτο}. χρόνου δὲ ἱκανοῦ διαγενομένου
κλεισθεῖσαι πάλιν ἠνοίγησαν αἱ θύραι, καὶ ἦν ἄλλη διάθε- 5
σις· αἱ γὰρ νῆες ἐφαίνοντο καθελκόμεναι ὑπὸ τῶν Ἀχαιῶν.
κλεισθεισῶν δὲ καὶ πάλιν ἀνοιχθεισῶν, οὐδὲν ἐφαίνετο ἐν
τῷ πίνακι πλὴν ἀέρος γεγραμμένου καὶ θαλάσσης.

(5) μετὰ δὲ οὐ πολὺν χρόνον παρέπλεον αἱ νῆες στολοδρο-
μοῦσαι· καὶ αἱ μὲν ἀπεκρύπτοντο, αἱ δὲ ἐφαίνοντο. πολλά- 10
κις δὲ παρεκολύμβων καὶ δελφῖνες ὅτε μὲν εἰς τὴν θάλατ-
ταν καταδύόμενοι, ὅτε δὲ φαινόμενοι, καθάπερ ἐπὶ τῆς
ἀληθείας. κατὰ μικρὸν δὲ ἐφαίνετο χειμέριος ἡ θάλασσα,
καὶ αἱ νῆες ἔτρεχον συνεχῶς. κλεισθέντος δὲ πάλιν καὶ
ἀνοιχθέντος, τῶν μὲν πλεόντων οὐδὲν ἐφαίνετο, ὁ δὲ Ναύ- 15
πλιος τὸν πυρσὸν ἐξηρκῶς καὶ ἡ Ἀθηνᾶ παρεστῶσα·

(6) καὶ πῦρ ὑπὲρ τὸν πίνακα ἀνεκαύθη, ὥς ἀπὸ τοῦ πυρ-
σοῦ φαινομένης ἄνω φλογός. κλεισθέντος δὲ καὶ πάλιν
ἀνοιχθέντος, ἡ τῶν νεῶν ἔκπτωσις ἐφαίνετο καὶ ὁ Αἴας
νηχόμενος, μηχανὴ τε {καὶ} ἄνωθεν τοῦ πίνακος ἐξήρθη 20

1 πρίζοντα A^{cp} G : περίθοντα T : θερίζοντα M πρίζοντα, <τὰ δὲ σκεπαρνί-
ζοντα> Schmidt dub. in app. crit. 3 <καὶ> R. Schöne πολύν AG : πολλήν
M καθάπερ <ἀν> R. Schöne 4 γίνοιτο delevi cum Schmidt (dub. in app.
crit.) 5 ἄλλη M : ἄλλην AG T 6 ἀχαιῶν A^{cp} G : ὀχαιῶν M^{cp} 9 πολὺν A
G : πολλήν M αἱ νῆες om. T¹ : add. T² 10-11 post πολλάκις graviter
interpunx. AG M et cett. edd. 11 δὲ huc transposui cum Schmidt (dub. in
app. crit.) : ante καὶ a παρεκολύμβων A^{pc} M : παρεκολύμβον A^{ac} G
12 post φαινόμενοι leviter interpunx. AG ed. princ. et Prou, graviter M : non
interpunx. Schmidt 13 κατὰ Haase : καὶ a 14 κλεισθέντος Prou : κλει-
σθέντα a an καὶ πάλιν? 15 ἀνοιχθέντος Prou : ἀνοιχθέντα a an ἀνοι-
χθέντος <τοῦ πίνακος>? 16 ἐξηρκῶς AG M : ἐξηρηκῶς Prou 17 ἀπὸ
Prou : ὑπὸ a 19 post ἐφαίνετο graviter interpunx. AG M, leviter ed. princ. et
Prou 20 post νηχόμενος leviter interpunx. Weil, graviter edd. : non
interpunx. AG M μηχανὴ Prou et R. Schöne, rec. Weil : μηχανῆς AG M :
<ἡ δὲ Ἀθηνᾶ ἐπὶ> μηχανῆς Diels : <***> μηχανῆς Schmidt τε AG M : δὲ
R. Schöne καὶ del. Weil post ἐξήρθη non interpunx. M et Prou : graviter
interpunx. AG, leviter ed. princ. et Schmidt

(4) These figurines moved, some sawing, some working with axes, some with hammers, some others using bow-drills and augers, <and> they made a lot of noise, just like in real life {may happen}. After sufficient time elapsed, the doors closed and opened again, and there was another arrangement; the ships, in fact, were shown being launched by the Achaeans. After they [the doors] closed and opened again, nothing appeared in the box except painted sky and sea.

(5) Not long after, the ships sailed in line ahead, and some were out of sight, some in view. Often dolphins swam alongside, too, sometimes plunging into the sea, sometimes visible, just like in real life. The sea gradually grew stormy, and the ships ran uninterruptedly. After it [the box] closed again and opened, none of the sailing ships was seen, but Nauplius holding up the torch and Athena standing beside him <were seen>;

(6) fire blazed up above the box, as if a flame appeared on high from the torch. After it [the box] closed and opened again, the wreck of the ships appeared, and Ajax swimming; and a machine was raised above the box, and as

καὶ βροντῆς γενομένης ἐν αὐτῷ τῷ πίνακι κεραυνὸς ἔπε-
σεν ἐπὶ τὸν Αἴαντα, καὶ ἠφανίσθη αὐτοῦ τὸ ζῶδιον. καὶ
οὕτως κλεισθέντος καταστροφὴν εἶχεν ὁ μῦθος. ἡ μὲν οὖν
διάθεσις ἦν τοιαύτη.

- XXIII** **(1)** Κατασκευάζειν δὲ δεῖ, καθάπερ ἐγράψαμεν, ἡλίκον ἂν 5
βούλοιτό τις τὸν πίνακα ποιεῖν, τηλικούτον τῷ μεγέθει
πλινθίον πήξαντας ἐκ σανίδων ἐλαφροτάτων πάνυ· πλάτος
δὲ ἐχέτωσαν αἱ σανίδες τὸ ἕκτον μέρος τοῦ μήκους τῶν
μακροτέρων πλευρῶν.
- (2)** τὸ δὲ ἔδαφος τοῦ πίνακος δεῖ καθαρμόζειν εἰς τὸ πλιν- 10
θίον μέσον, ὑπὸ δὲ τὸ κάτω μέρος τοῦ πλινθίου θωράκιον
κοῖλον ὑποπῆξαι ἄφανές εἰς τὸ ἔμπροσθεν μέρος, <ἐν> ᾧ
καθαρμοσθεισῶν τῶν θυρῶν καταβήσονται οἱ στροφεῖς
μῆκος ἔχοντες ὥστε καὶ τούτων κάτωθεν ἐπιστρεφομένων
ἀνοίγεσθαι καὶ πάλιν κλείεσθαι τὰς θύρας. 15
- (3)** ἔστω οὖν τὸ θωράκιον ἐκ τῶν ἔμπροσθεν θεωρούμενον
τὸ $\overline{\alpha\beta}$, στροφεῖς δὲ οἱ ἐκ τῶν θυρῶν καταβεβηκότες οἱ $\overline{\gamma}$, $\overline{\delta}$.
οὐκοῦν ἐάν τις ταῖς χερσὶν ἐπιστρέψῃ τοὺς στροφεῖς ἐφ’
ἐκάτερον μέρος, ἀνοίξει καὶ κλείσει τὰς θύρας. ἵνα οὖν

1-3 τῷ πίνακι... μῦθος alio loco iterant codices (τῷ πίνακι iterata esse noluerunt Prou et R. Schöne; vide infra, 3-4) 1-2 ἔπεσεν om. a (altero loco)
2 αὐτοῦ a (prioro loco) : αὐτὸ a (altero loco) τὸ A M G (altero loco) : τῷ G (prioro loco)
3 οὕτως a (prioro loco) : οὕτω δὲ a (altero loco) ordinem capitum antea confusum restituit Weil : post μῦθος in codicibus sequuntur Il. 80.1-84.11 οὕτως γίνεται... τοὺς τεκτονέοντας οὕτως, deinde iterum sequuntur Il. 1-3 τῷ πίνακι... μῦθος et Il. 74.3-78.19 ἡ μὲν οὖν διάθεσις... διδοῦσα. deinceps codices pergunt usque ad finem (Il. 84.12-110.15 κλεισθέντος δὲ... διαλλάσσονται) : similiter etiam R. Schöne, qui solum Il. 1-3 κεραυνὸς... μῦθος iterata cens. (hunc ordinem rec. Schmidt); vide Introductionem, p. xlvii-xlviii n. 84
5 caput distinx. Schmidt δὲ om. G ἐγράψαμεν A G M : an ὑπογεγράφαμεν? 6 τὸν A G : τὴν M T μεγέθει A G M : μήκει Schmidt dub. in app. crit. 7 πήξαντας Schmidt dub. in app. crit. : πήξας A G T : πίνῃξας M : πήξαντα R. Schöne 8 τὸ ἕκτον μέρος Schmidt dub. in app. crit. : τοῦ $\overline{\epsilon}$ μέρους A G M : † τοῦ ἕκτου μέρους Schmidt in textu 12 ἄφανές A G M : ἄχανές Brinkmann ante εἰς leviter interpunx. Prou ἔμπροσθεν Schmidt dub. in adn. crit., prob. Olivieri : ὀπισθεν A G M <ἐν> Schmidt dub. in app. crit. ᾧ A G M Ph (in textu) : ᾧ Ta : οὗ Ph (dub. in mg.) 17 καταβεβηκότες A^{cp} G M : καταβεβηκότες T 18 τοὺς A^{cp} M^{cp} T : τοῦ G

thunder rumbled in the box itself a bolt of lightning fell on Ajax, and his figure vanished. Thus, when the box closed, the story came to an end. So, such was the arrangement.

xxiii **(1)** It is necessary to construct a frame the size one would want to make the box, as I have illustrated, and to build it out of exceptionally lightweight boards; let the boards be one-sixth as wide as the length of the longer sides.

(2) The backdrop of the box must be fitted into the middle of the frame, and under the lower part of the frame a hollow enclosure must be attached, which is invisible from the front; after the doors have been fixed <to> this, pivots will run down such a length that, when these are turned from below, the doors open and close again.

(3) Thus, let there be the enclosure seen from the front, $\overline{\alpha\beta}$, and pivots going down from the doors, $\overline{\gamma}$ and $\overline{\delta}$. Then, if someone turns the pivots on each side by hand, they will open and close the doors. So, in order for this to happen

Fig. 28

τοῦτο διὰ τῆς σπάρτου γίνηται αὐτόματον, ἐλκομένης αὐτῆς ὑπὸ τῆς λείας ἐν τῇ σύριγγι οὔσης ἐπὶ τῆς ψάμμου, παρατίθημι τοῖς στροφεῦσιν ἄξονα πλάγιον ἀφεστῶτα μικρὸν τῶν στροφῶν τὸν εἴ, στρεφόμενον εὐλύτως.

(4) ἐτρύπησα δὲ ἐκάτερον τῶν στροφῶν καὶ λαβὼν σπάρτον ἐπέειψα διπλὴν καὶ ἐνέβαλον τήνδε ἀπλὴν εἰς τὸ τρύπημα καὶ ἐπίουρον μετὰ κόλλης ἐνέκρουσα καὶ ἀπέλαβον αὐτήν, ὥστε μηκέτι ἐκσπᾶσθαι, ἀλλὰ μένειν ἀραρότως. τοῦτο δὲ ποιήσας ἀποκατέστησα τὰς ἀρχὰς περὶ τὸν ἄξονα τὴν μὲν κατὰ τὸ γδ ἄνωθεν τοῦ ἄξονος, τὴν δὲ κατὰ τὸ εἴ κάτωθεν.

(5) τρυπήσας ὁμοίως τὸν ἄξονα ἐκάστην ἀρχὴν ἀπέλαβον ἐπιούροις ἀραρότως τισίν, <διατείνας> εὖ μάλα τὰς σπάρτους, τὴν <μὲν> κατὰ τὸ ε, <τὴν δὲ> κατὰ τὸ ζ. αἱ δὲ σπάρτοι ἐπιστρέψουσι τοὺς στροφεῖς καὶ ἀνοίξουσιν τὰς θύρας. ὅταν δὲ πάλιν τὰ ἐναντία ἐπιστρέφω τὸν ἄξονα, †καὶ μέντοι† ἀνεθήσονται, <***> ὅθεν κλεισθήσονται αἱ θύραι.

1 γίνηται AG^{cp} : γένηται M 3 ἀφεστῶτα Haase : ἐφεστῶτα a 4 εὐλύτως scripsi : ἐντόρνω a, quod rec. Schmidt, ex glossemate ortum existimo : εὐτόρνω R. Schöne 6 καὶ ἐνέβαλον τήνδε Schmidt in textu : καὶ ἐνέβαλον τὴν δὲ AG M : {καὶ} τὴν δὲ ἐνέβαλον Schmidt dub. in app. crit. antea leviter interpungens : καὶ ἐνέβαλον <***> τὴν δὲ Brinkmann 8 μένειν AG : μὴν M 9 περὶ AG M : παρὰ Schmidt dub. in app. crit. 10 τὴν μὲν κατὰ τὸ γδ AG M : τὰς μὲν κατὰ τὰ γ, δ Schmidt dub. in app. crit. : an τὴν μὲν {κατὰ τὸ γδ}? 10-11 τὴν δὲ κατὰ τὸ εἴ AG M : τὰς δὲ κατὰ τὰ ε, ζ Schmidt dub. in app. crit. : an τὴν δὲ {κατὰ τὸ εἴ}? 11 τὸ om. T 12 τρυπήσας <δὲ> Brinkmann dub. <καθ'> ἐκάστην Schmidt dub. in app. crit. : <***, καὶ ἐγκρούσας (vel sim.)> ἐκάστην Brinkmann 13 τισίν ἀραρότως Brinkmann post τισίν leviter interpunxi, graviter AG M : non interpunx. edd. <διατείνας> supplevi 13-14 τὰς σπάρτους AG M : τῶν σπάρτων Prou, iungens cum ἐκάστην ἀρχὴν (12) 14 τὴν <τε> Schmidt dub. in app. crit. <μὲν> supplevi post ε leviter interpunx. ed. princ. : non interpunx. AG M, Prou et Schmidt <τὴν δὲ> supplevi κατὰ² scripsi : καὶ AG M : καὶ <τὴν κατὰ> Schmidt dub. in app. crit. 15 σπάρτοι <ταθεῖσαι> Schmidt dub. in app. crit. 17 καὶ μέντοι AG T : καὶ αἱ μέντοι M : cruces posui secutus Schmidt, qui αἱ μὲν <ταθεῖσαι σπάρ>τοι dub. conl. in app. crit. : an {καὶ} αἱ μὲν σπάρτοι? ἀνεθήσονται a : ἀνεχθήσονται Pc : ἀνοιχθήσονται Prou lacunam statuit Schmidt, qui <οἱ δὲ στροφεῖς πάλιν τὰ ἐναντία ἐπιστραφήσονται> dub. suppl. in app. crit.

automatically by means of the cord, when it is pulled by the counterweight which is on the sand in the tube, I place a freely revolving axle $\overline{\varepsilon\zeta}$ across the pivots and at a small distance from them.

(4) I bored a hole in each of the pivots and, taking a cord, wound it double, put this single cord into the hole, drove a peg in adding glue and secured it, so that it would not pull out any further, but remain tightly fastened. Having done this, I laid the ends around the axle, one over $\overline{\gamma\delta}$ from above the axle, the other over $\overline{\varepsilon\zeta}$ from below.

(5) After likewise piercing the axle, I secured each end firmly with some pegs, carefully <stretching> the cords <to the utmost>, one at $\overline{\varepsilon}$, <the other at> $\overline{\zeta}$. The cords will rotate the pivots and open the doors. Whenever I turn the axle the other way around, †and in fact† they [the cords] will be slackened, <***> whence the doors will close.

(6) οὕτως οὖν ἀπὸ μιᾶς κινήσεως ἅμα ἀμφότεραι αἱ θύραι
 <ὅτε μὲν> κλεισθήσονται, ὅτε δὲ ἀνοιχθήσονται. ἵνα οὖν
 διὰ τῆς λείας <αὐτόματον> τοῦτο γίνηται, ἐνέπηξα τύλους
 εἰς τὸν ἄξονα ἄνωθεν ἐφ' ὧν τὰ η καὶ κάτωθεν ἐφ' ὧν τὰ
 θ , καὶ λαβὼν σπάρτον καὶ καταμετρησάμενος τὸ μήκος 5
 πρὸς τὴν σύριγγα τὴν ἔχουσιν τὴν ψάμμον καὶ <τὴν>
 λείαν, ἐν ὁποίοις δὲν ἦ διαστήμασιν, ἦψα ἀγκύλας. καὶ
 ἔστω σπάρτος μὲν ἡ κ , ἀγκυλῖναι δὲ αἱ λ .

(7) τὴν πρώτην οὖν ἀγκύλην τὴν ἀπὸ τοῦ κ περιτίθημι
 περὶ τὸν τύλον τὸν πρῶτον τὸν ἀπὸ τοῦ ϵ , ἐφ' <οὐ> τὸ η , 10
 τὴν δὲ ἐχομένην ἀγκύλην περὶ τὸν κάτω τύλον τὸν θ καὶ
 οὕτως ἐξῆς πάσας προσκολλῶν αὐτὰς περὶ τὸν $\epsilon\zeta$ ἄξονα
 κηρῷ {τε} μετὰ ῥητίνης. {ἔστι δὲ κεκαλυμμένον τοῦτο
 παρακόλλημα.}

(8) καὶ τὰ παραχαλασμάτια αὐτῶν πρὸς τὸν ἄξονα προσ- 15
 κολλῶ, ἵνα μὴ τινὰ αὐτῶν ταραχθέντα δυσέργειαν παρέχ-
 ται. ὅταν οὖν ἡ ἀρχὴ τῆς σπάρτου, ἐφ' ἧς ἔστι τὸ κ , ἐκδε-
 θεῖσα ἐκ τῆς λείας ἔλκεται πράως, ἀνοίξει καὶ κλείσει τὸν
 πίνακα χρόνους καὶ διαλείμματα διδοῦσα.

1 ἀπὸ AG M : ὑπὸ Brinkmann 2 <ὅτε μὲν> Schmidt ὅτε AG : ὅταν MT
 3 <αὐτόματον> Schmidt secutus Haase (huc transposito ex post γίνηται)
 6 <τὴν> Schmidt dub. in app. crit. 7 δὲν (= δὴ ἄν) Brinkmann : δὲ ἄν a : δ'
 ἄν Ta ἦψα AG : ἦψα M : corr. Schmidt 8 ἀγκυλῖναι AG^{pcsl} M : ἀγγυλῖ-
 ναι G^{ac} : ἀγκύλαι Schmidt dub. in app. crit. λ AG : δ M 9 πρώτην Prou
 dub. : $\alpha^{\eta\nu}$ M^{cp} : α AG T περιτίθημι AG : περὶ τίθημι M^(περὶ cp) 10 τὸν
 <ἄνω> τύλον Schmidt dub. in app. crit. πρῶτον Bb : α^{ν} Tb : α a ἐφ'
 Brinkmann : ἐπὶ a : περὶ Schmidt dub. in app. crit. <οὐ> Brinkmann τὸ A
 G M : τὸν Schmidt dub. in app. crit. 11 ἐχομένην Schmidt dub. in app. crit. :
 ἐσομένην a : ἐπομένην Prou τὸν² A^{cp} M : τὸ G 13 τε del. Schmidt
 13-14 ἔστι...παρακόλλημα delevi cum Schmidt (dub. in app. crit.), prob.
 Olivieri κεκαλυμμένον AG : καλυμμένον M^{cp} τοῦτο <τὸ> Schmidt dub.
 in app. crit. 15-16 προσκολλῶ AG : προκολλῶ T : προσκολλῶ M 16 τα-
 ραχθέντα Schmidt : ταραχθέντων a : παραχθέντα Prou 17 τῆς AG : τοῦ M
 18 τῆς λείας M^{cp} : τὴν λείαν AG T

(6) So, in this way both doors will close <at one moment>, and open at the next, simultaneously with one motion. Thus, in order for this to happen <automatically> by means of the counterweight, I thrust knobs into the axle – above where the <points> $\bar{\eta}$'s <are> and below where the <points> $\bar{\theta}$'s <are> – and having taken a cord and measured its length against the tube containing the sand and <the> counterweight, I made loops at intervals of whatever size. Let there be a cord, $\bar{\kappa}$, and loops, $\bar{\lambda}$'s.

(7) Therefore, I put the first loop from the <point> $\bar{\kappa}$ around the first knob from $\bar{\epsilon}$, where the <point> $\bar{\eta}$ <is>, and the next loop around the lower knob $\bar{\theta}$, and thus gluing them all one after another around the axle $\bar{\epsilon}\zeta$ with a compound of wax and resin. {This gluing has been concealed.}

(8) I also glue their slack parts onto the axle, so that none of them may become tangled up and hamper the mechanism. So, whenever the end of the cord (where the <point> $\bar{\kappa}$ is), is pulled gently being fastened to the counterweight, it will open and close the box, providing the timings and intervals.

(1) <Ταῦτα μὲν οὖν> οὕτως γίνεται. γενομένης <δὲ> τῆς πρώτης ἀνοίξεως ἡμῖν ἐστί πωσ† ἐν τῷ πίνακι φανῆναι ζῳδία τεκταίνοντα, περὶ <ὧν> ἐμφανίσαι δεῖ τίνι τρόπῳ τὴν κίνησιν λαμβάνει. δεῖ οὖν τὰ μὲν ἄλλα πάντα μέρη τῶν ζωδίων ἐν τῷ ἐδάφει τοῦ πίνακος γεγράφθαι διαθέσεις 5 ἔχοντα πιθανωτάτας, τὰς δεξιὰς δὲ χεῖρας μὴ γεγραμμένας <εἶναι> ἐν τῷ πίνακι, προσκεῖσθαι δὲ κερατίνας ἐξ ἐλαφρῶν κεράτων λεπτὰς εὖ μάλα κατειργασμένας, ἵνα προσπίπτωσι καὶ μηδὲν δῆλον ἀπόστημα ἔχωσι.

(2) δεῖ δὲ καὶ τὰ ἀρμένια, ἐν οἷς ἐργάζονται, κεράτινα εἶναι, προσκεῖσθαι δὲ ἐν ταῖς χερσὶ καὶ ἀπογεγράφθαι τὰς χεῖρας ὁμοχρόους τοῖς ἄλλοις σώμασι, καὶ τὰ ἀρμένια ὡς προσῆκόν ἐστιν. 10

ἔστω οὖν ἡ χεὶρ ἡ $\overline{\alpha\beta}$. ἐτρύπησα οὖν αὐτὴν κατὰ τὸν ὦμον καὶ ἐποίησα τὸ τρύπημα τετράγωνον, ὡς γέγραπται, 15 καὶ λαβὼν κεράτινον ἐπίουρον ἐνήρμοσα εἰς μὲν τὸν ὦμον

1 caput distinx. Schmidt <Ταῦτα μὲν οὖν> Schmidt : <καὶ ταῦτα μὲν> Weil γενομένης Weil : γινομένης A^{pcp} G M^{cp} : γινόμενα A^{accp} <δὲ> Weil 2 cruces posui secutus Weil : fort. transposito ἡμῖν post <δὲ> totus locus ita legendus est: γενομένης <δὲ> ἡμῖν τῆς πρώτης ἀνοίξεως ἔστιν <εὐκό>πως ἐν τῷ πίνακι φανῆναι ζῳδία τεκταίνοντα post ἡμῖν lacunam statuit Schmidt, qui <ὑποδεικτέον> dub. suppl. in app. crit. post ἐστί non interpunx. A G Med. princ. et Prou : leviter interpunx. Schmidt πωσ a : πῶς Ac Lb Ld O Ta Vd post πῶς lacunam statuit Schmidt, qui <ἔστι> vel <δυνατόν ἐστι> dub. suppl. in app. crit. 3 post τεκταίνοντα leviter interpunx. G et Prou, graviter A Med. princ. et Schmidt <ὧν> Weil περὶ ἐμφανίσαι Ab Ac Ad : περιεμφανίσαι A G T : περὶ ἐμφανίσας M : περὶ... ἐμφανίσαι Brinkmann : προσεμφανίσαι Schmidt dub. in app. crit. : παρεμφανίσαι Haase δεῖ Weil : δὲ A G M, quo servato lacunam post hoc verbum statuit Schmidt : δὲ <δεῖ> Schmidt dub. in app. crit. 6 πιθανωτάτας Mc O Pb Ta Vd : πειθανωτάτας a 7 <εἶναι> Schmidt dub. in app. crit. 7-8 an ἐξ ἐλαφρῶν κεράτων delenda? 7-8 ἐλαφρῶν A G T : ἐλαφῶν M 8-9 προσπίπτωσι A^{pcp} M : πρὸςπίπτωσι A^{accp} : προπίπτωσι G 12 ὁμοχρόους A G : ὁμοχόρους T : ὁμόρους M ἄλλοις A G M : an ὅλοις? σώμασι A G M : σωμά<των μέρε>σι Schmidt dub. in app. crit. post σώμασι leviter interpunx. A G et Prou : non interpunx. Med. princ. et Schmidt post ἀρμένια non interpunx. A G M et ed. princ. : leviter interpunx. Schmidt et Prou 14 ἐτρύπησα A G M^{pc} : ἐτρύπησας M^{ac} : ἡτρύπησα T αὐτὴν A G M^{cp} : αὐτοὺς T 15 γέγραπται A G M : ὑπογέγραπται Schmidt dub. in app. crit. 16 ἐνήρμοσα A G M : ἐν ἥρασμοσα T

xxiv **(1)** <So, this> takes place in this way. After the first opening of the doors, †it is for us somehow† figurines carrying out joinery work to appear in the box; and it is necessary to explain how they receive their motion. Thus, while all the other parts of the figurines must be painted on the backdrop of the box and arranged in the most convincing way, the right arms must not <be> painted on the box, but attached to it and very carefully wrought out of thin pieces of light horn, so as to fit closely and leave no visible gap.

(2) The small tools, with which they work, must be of horn too and set in their hands, and the hands painted the same colour as the rest of the body, and the small tools as is appropriate.

So, let there be the hand and arm, $\overline{\alpha\beta}$. Thus, I pierced it with a hole through the shoulder and made the hole square, as has been illustrated, and after taking a horn peg and squaring it off I fitted it into the shoulder and glued it

τετράγωνον ποιήσας καὶ ἐνεκόλλησα, τὸ δὲ λοιπὸν τοῦ ἐπιούρου <ἐποίησα> στρογγύλον καὶ λείον καλῶς.

(3) τρυπήσας δὲ κατὰ τὸν δεξιὸν ὦμον ἐδίωσα τὸν ἐπίουρον καλῶς, ἕως οὗ προσκαθήσῃ τὸ χέριον εἰς τὸ ζώδιον. ἐὰν οὖν καταλάβωμεν τοῖς δακτύλοις ἐκ τῶν ὀπισθεν μερῶν τοῦ πίνακος τὸ ὑπερέχον τοῦ ἐπιούρου στρέφοντες, 5
κινηθήσεται τὸ χέριον. ὅπως οὖν ὑπὸ τῆς λείας αὐτόματον κινήται, ποιῶ κανόνιον τὸ $\overline{\gamma\delta}$ καὶ τρυπῶ κατὰ τὸ $\overline{\theta}$ καὶ τὸν ἐπίουρον τὸν ἐκ τῆς χειρὸς ὑπερέχοντα εἰς τὸ ὀπισθεν μέρος τοῦ πίνακος ἐναρμόζω εἰς τὸ τοῦ κανονίου τρύπημα 10
ἀραρότως καὶ ἐγκολλῶ, ἵνα κινουμένου τοῦ κανονίου κινήται καὶ τὸ πρὸς τῷ ὦμῳ.

(4) τὸ δὲ κανόνιον τοῦτο καλεῖται ὑσπλήγγιον. εἰς τὸ ἐν οὖν μέρος τοῦ ὑσπληγγίου τρυπήσας ἐξέδησα σπάρτον καὶ ἐκρέμασα λείαν μολιβδίνην τὴν $\overline{\iota}$ καὶ ὑπέπηξα ἐπίουρον 15
ὑπὸ τὸ ἄκρον τοῦ ὑσπληγγος, τὸν $\overline{\zeta}$, ἵνα ἐπαναπαύηται τοῦ ὑσπληγγίου τὸ ἄκρον. οὐκοῦν ἐὰν τῷ δακτύλῳ καταβαρῇσωμεν τὸ ὑσπλήγγιον κατὰ τὸ $\overline{\gamma}$ μέρος, μετεωρισθήσεται τὸ $\overline{\delta}$ μέρος σὺν τῇ λείᾳ· ἐὰν δὲ ἀφῶμεν, καταπεσεῖται ἐπὶ τὸν ἐπίουρον ἐπισπωμένης τῆς λείας καὶ ψόφον ποιήσει. 20

(5) ἐπιδώσει δὲ καὶ τῇ χειρὶ τὴν κίνησιν ἐν τῷ ἔμπροσθεν μέρει τοῦ πίνακος. ἵνα οὖν πυκνῶς καὶ αὐτομάτως κινήται,

1 ἐνεκόλλησα Ta^(dub. in mg.) : ἐνεκώλυσσα a Ta^(in textu) 2 <ἐποίησα> Schmidt dub. in app. crit. 3 post δὲ fort. lacuna statuenda, in qua <τὴν χεῖρα> vel <τὸ χέριον> fuit (nisi κατὰ delendum est) : δὲ <τὸ ζώδιον> Brinkmann τὸν¹ scripsi secutus Schmidt, qui <τὸν> post κατὰ dub. suppl. in app. crit. : τοῦ A G M, quo servato <ζωδίου> post hoc verbum dub. suppl. Schmidt in app. crit. δεξιὸν ὦμον Schmidt dub. in app. crit. : δεξιὸν ὦμου A G M † ἐδίωσα Schmidt 5 οὖν om. M T 8 τρυπῶ A G : τρύπημα M T 12 τὸ πρὸς τῷ ὦμῳ <χερίον> (sic) Schmidt dub. in app. crit. : τὸ <χερίον> (sic) τὸ > πρὸς τῷ ὦμῳ Brinkmann 13-14 οὖν ἐν M ἐν A G M : ἕτερον Schmidt dub. in app. crit. 15 $\overline{\iota}$ A G M : $\overline{\epsilon}$ Schmidt dub. in app. crit. 16 ὑπὸ Schmidt : ἐπὶ a τὸν scripsi : τὸ A G M ἐπαναπαύηται A G : ἐπαναπαύεται T : ἐπαναπαύσαι M¹ : ἐπαναπαίσαι M^{2mg} : ἐπαναπαύηται <ἐπὶ τούτου> Schmidt dub. in app. crit. 17-18 καταβαρήσωμεν Tb : κάτω βαρήσωμεν A G M

on; <I made> the rest of the peg rounded and thoroughly smooth.

(3) Having bored a hole through the right shoulder, I thrust the peg in properly, until the small arm has drawn near to the figurine. So, if we seize the projecting part of the peg with our fingers from the back of the box and turn it, the arm will move. Therefore, in order for it to move by itself under the impulse of the counterweight, I make a bar, $\overline{\gamma\delta}$, pierce it with a hole at $\overline{\theta}$, insert the peg jutting out from the arm towards the back of the box tightly into the hole of the bar and glue it on, so that, as the bar moves, that <which originates> in the shoulder may move too.

Fig. 29

(4) This bar is called *hysplēngion*. So, after boring a hole at one side of the *hysplēngion*, I fastened a cord to it, hung a lead counterweight, $\overline{\iota}$, and fixed a peg under the extremity of the *hysplēnx*, $\overline{\zeta}$, so that the end of the *hysplēngion* may come to rest on it. Then, if we will press down the $\overline{\gamma}$ side of the *hysplēngion* with our finger, the $\overline{\delta}$ side will be raised together with the counterweight; and if we let it go, it will fall down on the peg as the counterweight pulls it, and it will make a noise.

(5) It will also transmit movement to the arm at the front of the box. So, in order that it may move frequently and

παρατίθημι {τὸν} ἀστερίσκον στρεφόμενον περὶ ἐπίουρον
ἐμπεπηγότα τῷ ἐδάφει τοῦ πίνακος ἀραρότως. ἔξει δὲ ὁ
ἀστερίσκος προσόντα αὐτῷ προσφυῇ τροχίλον τὸν $\bar{\eta}$, περὶ
ὃν ἡ σπάρτος περιειληθεῖσα πολλάκις ἀποδοθήσεται τῇ
λείᾳ, ἵνα ἐπισπωμένη ἡ λεία κατὰ μικρὸν ἐπιστρέφῃ τὸν
ἀστερίσκον καὶ ὁ ἀστερίσκος ταῖς στροφαῖς τὸν ὕσπληγγα
κρούῃ πυκνά.

(6) τὸ δὲ ἔσχατον μέρος τῆς σπάρτου ἀγκυλωθὲν περὶ τὸν
τύλον περιτίθεται ἐφ' οὗ τὸ $\bar{\eta}$. ὅταν <***> μηκέτι τὴν
χεῖρα κινεῖσθαι, ἀποσχασθεῖσα ἀπὸ τοῦ τύλου †περιγνοίη†

XXV (1) Τὰ μὲν <οὖν> περὶ τοὺς τεκτονεύοντας οὕτως <γίνε-
ται>. κλεισθέντος δὲ καὶ μετὰ ταῦτα ἀνοιχθέντος <τοῦ
πίνακος>, δεῖ τοὺς μὲν τεκτονεύοντας μηκέτι φαίνεσθαι,
τὰς δὲ ναῦς καθελκομένας.

(2) γίνεται οὖν καὶ τοῦτο, καθὼς μέλλομεν λέγειν. ὁθόνιον
δεῖ λαβεῖν λεπτὸν καὶ πυκνόν, ἴσον ἔχον μέγεθος τῷ τοῦ
πίνακος ἐδάφει, τοῦτο δὲ χρίσαντας ὑγροτάτῳ λευκῷ χρω-

1 ἀστερίσκον τὸν Schmidt dub. in app. crit. : τὸν ἀστερίσκον <τὸν $\bar{\epsilon}$ >
Brinkmann τὸν delevi 3 αὐτῷ Prou : αὐτῷ a 4 ὃν AG : οὗ M 5 ἵνα
AG : ἵν' M ἐπιστρέφῃ F (in textu) : ἐπιστρέφει a F^{mg} 7 κρούει a : corr. Prou
8-9 τὸν τύλον M : τοῦ τύλου AGT 9 ὅταν a : ὅπως ἂν Prou lacunam
statui secutus Schmidt, qui ὅταν <δὲ δέη> μηκέτι dub. conl. in app. crit. : <ἵν'>
ὅταν μηκέτι <χρεία ἦ> Brinkmann : fort. ὅταν <δὲ βουλόμεθα> vel ὅταν <δὲ>
μηκέτι <βουλόμεθα> †μηκέτι Schmidt 10 ἀποσχασθεῖσα om. T cruces
posui secutus Schmidt : περιγνοίη AGT, quo deletο <ἡ ἀγκύλη ἐκπίπτει>
dub. suppl. Schmidt in app. crit. : περιγνοίας Ab^{ac} : περὶ γνοίας M : περνας
Ab^{pc} : περιγνοίης (sic) Prou 11-12 οὐκ ἔστι συνεχὴς ὁ λόγος οὗτος A^{mg} G^{mg}
: λείπει M^{mg} (de ordine capitum vide ad 74.3) <οὖν> Prou τεκτονεύοντας
A^{cp} G : τεκτονεύονται M οὕτως <ἐν> Prou (servatis verbis iteratis τῷ πί-
νακι), rec. Schmidt 11-12 <γίνεται> Prou, rec. Schmidt 12 καὶ A^{cp} M^{cp} T²
: εἰς T¹ : om. G 12-13 <τοῦ πίνακος> supplevi 15 ὁθόνιον AGM : ὀρθο-
γόνιον Pg^{ac} : ὀρθογόνιον Pg^{pcsl} 16 δεῖ λαβεῖν Pg^{pcsl} : διαλαβεῖν a ἔχον A^{cp}
G : ἔχειν M τῷ AGM : τὸ T 17 χρίσαντας Schmidt : χρίσαντες A M^{pcsl} :
χρήσαντες G M^{ac}

automatically, I place {the} a starwheel revolving around a peg securely fixed to the backdrop of the box. The starwheel will have a pulley $\bar{\eta}$ tightly fastened to it; having been wound several times around this [the pulley], the cord will be attached to the counterweight, so that, as the counterweight draws <the cord>, it may slowly turn the starwheel and the starwheel may hit the *hysplēnx* repeatedly while rotating.

(6) Having been looped, the furthest end of the cord is put around the knob where $\bar{\eta}$ <is>. When <***> no longer to move the arm, it [the cord?] having been released off the knob†

xxv (1) <So,> woodworkers' activities <take place> in this way. After <the box> has closed and subsequently opened, the woodworkers must no longer be seen, but the ships <must be seen> as they are launched.

(2) This too, then, occurs, as I am going to say. It is necessary to take a thin and closely woven piece of linen cloth, which is the same size as the backdrop of the box, and after dying this with white and exceedingly fluid paint, so

ματίῳ, ἵνα εὐλύτως δύνῃται συνειλεῖσθαι, ζωγραφῆσαι τὰς
καθελκομένας ναῦς καὶ προσθέντας πρὸς τὸν πίνακα τὸ
μὲν ἄνω μέρος προσηλῶσαι κεντρίοις πρὸς τὸ τοῦ πίνακος
ἐπίπεδον ὑπ' αὐτὴν τὴν τοῦ πλινθίου πλευρὰν, πρὸς δὲ τὸ
κάτω μέρος τοῦ ὀθονίου προσάψαι χαλκοῦν ὀβελίσκον δι' 5
ὅλου πάχος ἔχοντα σύμμετρον,

(3) ἵνα εἰλοῦντες περὶ τὸν ὀβελίσκον τὸ ὀθόνιον εἰς τὸ
ἄνω μέρος τοῦ πίνακος καὶ συστρέψαντες καλῶς κρατή-
σωμεν ὑπὸ τὴν πλευρὰν τοῦ πλινθίου καί, ὅταν βουλώ-
μεθα, ἀφῶμεν· ἀφεθὲν δὲ τὸ ὀθόνιον ἐξελίσσεται ὑπὸ τοῦ 10
βάρους τοῦ ὀβελίσκου καὶ συντόμως ἀπειλίσσόμενον κα-
λύψει τὰ ἐν τῷ πίνακι γεγραμμένα.

(4) τοῦτο οὖν δεῖ γενέσθαι κεκλεισμένου τοῦ πίνακος αὐ-
τόματον. ἐν δὲ τῷ πρότερον δεῖ μένειν αὐτὸ συνειλημένον
ἄνω. γίνεται οὖν οὕτως. ὅταν εἰληθῇ καλῶς εἰς τὸ ἄνω 15
μέρος καὶ τεθῇ ὑπὸ τὴν πλευρὰν τοῦ πλινθίου, ὑποκάτω
τοῦ εἰλήματος παρ' αὐτῷ ἐτρυπήθη εἰς τὸ ἔδαφος τοῦ
πίνακος <τρύπημα>, καὶ ὠθήθη διὰ τοῦ τρυπήματος ἐκ
τοῦ ὀπισθεν μέρους τοῦ πίνακος εἰς τὸ ἔμπροσθεν μέρος
ἀγκύλη σπάρτου, ἕως μὲν προσχῇ σύμμετρόν τι διάστημα 20
καὶ ἐπιούρῳ ἀποληφθῇ ἀραρότως.

1 συνειλεῖσθαι M : συνειλήσθαι A G^{pcsl} T : συνηλεῖσθαι G^{ac} 2 προσθέντας
Schmidt : προσθέντες a 3 προσηλῶσαι Ta : προσηλωσθαι a κεντρίοις
Prou : κοντρίοις a 5 προσάψαι Aa^{pc} : προσγράψαι A G Aa^{ac} : προγράψαι M
T 8-9 κρατήσωμεν A^{cp} G M^{cp} : καταθῶμεν Schmidt dub. in app. crit.
10 post ἀφῶμεν graviter interpunx. A G Med. princ. et Prou, leviter Schmidt
ἐξελίσσεται Ab Ac Ld : ἐξελίσσεται A^{pcsl} M^{pcsl}, rec. Schmidt : ἐξελίσσεται A^{ac}
G M^{ac} 11 ἀπειλίσσόμενον Schmidt : ἀπειλησόμενον A G T : ἀπειλησόμε-
νον M^{cp} 11-12 καλύψει a : καλύψη Haase, rec. Schmidt 14 πρότερον
Schmidt dub. in app. crit. : προτέρῳ A G M 15 οὖν <τοῦτο> Schmidt dub.
in app. crit. 16-17 τοῦ πλινθίου... εἰς om. T¹ : add. T^{2mg} 18 <τρύπημα>
supplevi ὠθήθη A G M : ἀν ὥσθη? ἐκ A G : τὸ ἐκ M T 20 ἀγκύλη Prou
: ἀγκύλης a σπάρτου Aa^{2sl} : παρὰ τοῦ a Aa¹ προσχῇ Prou : προείχε a :
προέχῃ Schmidt dub. in app. crit. 21 ἐπιούρῳ A G : ἐπὶ οὐρῳ M

that it may easily be rolled together, <it is necessary> to paint the ships being launched; holding it against the box, <one must> tack its upper part to the surface [the back-drop] of the box under the side itself of the frame, and fasten a bronze rod that has an entirely appropriate thickness to the underside of the cloth,

(3) so that, when we wind the cloth around the rod towards the upper part of the box and when we roll it up completely, we may hold it <in place> under the side of the frame, and let it go whenever we want; once released, the cloth will be unrolled by the weight of the rod, and by being unrolled in a trice it will cover the figures painted in the box.

(4) So, this must happen automatically, with the box closed. At the beginning it [the cloth] must remain rolled together above. It takes place as follows. When <the cloth> was wholly wound towards the upper part and put under the side of the frame, <a hole> was bored below the roll near it into the backdrop of the box, and a loop of cord was pushed through the hole from the back of the box to the front, until it jutted out a moderate distance and was firmly secured with a peg.

(5) ἡλίκον δὲ δεῖ εἶναι, αὐτὸ τὸ πρᾶγμα δείξει. εἴτα κατ' αὐτὸ τὸ ἐν τῷ ἐδάφει τρύπημα τρυπῶ παρὰ τὴν πλευρὰν τοῦ πλινθίου τρύπημα εὐρύτερον τοῦ κάτω καὶ διαρρινῶ αὐτό, ὅπως πλείω†. <***> καὶ περὶ τοῦτο εἰλημένου τοῦ ὀθονίου περισφίγξαι εἰς τὴν ἀγκύλην καὶ διώσαι διὰ τρυπηματίου τοῦ ἐν τῇ πλευρᾷ καὶ ἄνωθεν περόνιον διώσας διὰ τῆς ἀγκύλης.

5

(6) μένει οὖν συνεσφιγμένον τὸ εἶλημα τοῦ ὀθονίου συνεχόμενον ὑπ' αὐτῆς. ὅταν δὲ δέη καλυφθῆναι τὰ ἐν τῷ πίνακι, κεκλεισμένων τῶν θυρῶν, ἐκσπάσαι τὴν σπάρτον τὴν προσδεδεμένην τῇ περόνῃ, ἀποδεδομένην δὲ εἰς τὴν λείαν. οὕτως οὖν πάντα τὰ ἐπικαλύπτοντα ἐποιεῖτο, συνειληθέντα καὶ ἐξῆς ἄνω ἐπάλληλα τεθέντα καὶ ἕκαστον αὐτῶν ἀγκύλην καὶ περόνην λαβόν.

10

1 κατ' A G M^{cp} : an παρ'? 2 τρυπῶ Prou : τρυπᾶν A^{ac} G : τρυπῶ A^{pc} (ut videtur) : τρύπημα T : om. M παρὰ A G M : an κατὰ? 3 διαρρινῶ Prou : διαρινῶ A G M^{ac} T : διακρινῶ M^{pcsl} 4 ὅπως πλείω inter cruces posui †πλείω Schmidt, qui λειῶ dub. conl. in app. crit. : λείωται (sic) ed. princ. (dub. in mg.) : an <ἐπὶ πλείστον> λειῶται vel sim.? : post πλείω non interpunx. Prou lacunam statui περὶ τοῦτο A^{pc} G M : περὶ τούτου A^{ac} : †περὶ τοῦτο Schmidt, qui παρὰ τοῦτο (i.e. τρύπημα) dub. conl. in app. crit. : περόνην τὸ Prou : an περὶ τούτον (i.e. ὀβελίσκον)? εἰλημένου F : εἰλημένον A G M : †εἰλημένον Schmidt, qui ante hoc verbum <τὸ> dub. suppl. in app. crit. : εἶλημα Prou 5 περισφίγξαι A G M : περισφίγξαι Vd : †περισφίγξαι Schmidt, qui <δεῖ> περισφίγξαι vel tantum περισφίγξαι dub. conl. in app. crit. post ἀγκύλην graviter interpunx. Prou, leviter ed. princ. <δεῖ δὲ> καὶ Prou 5-7 διὰ τρυπηματίου... διὰ om. T¹ : add. T^{2mg} 5-6 τρυπηματίου A G M : τρυπήματος F 6 ἄνωθεν περόνιον post καὶ (5) transponenda dub. cens. Schmidt, mutato περόνιον in περόνην διώσας delendum dub. cens. Schmidt 9-10 πίνακι <γεγραμμένα> Schmidt dub. in app. crit. 10 ἐκσπάσαι Tb : ἐκσπάσαι A G M : <δεῖ> ἐκσπάσαι vel tantum ἔκσπασαι Schmidt dub. in app. crit. 11 ἀποδεδομένην A^{cp} G^{cp} M^{cp} : ἀποδεδεμένην Prou 12 οὕτως G^{ac} : οὕτω A G^{pc} M T ἐπικαλύπτοντα Schmidt dub. in app. crit. : ἐπικαλυπτόμενα A G M 13 καὶ! om. G {καὶ} ἕκαστον (mutato λαβόν (14) in λαβόντος) vel <ὥστε> {καὶ} ἕκαστον (mutato λαβόν (14) in λαβεῖν) Schmidt dub. in app. crit. 14 λαβόν A G T : λαβόν M

(5) The particular case will indicate how great <the distance> must be. Then, over against the hole itself in the backdrop I pierce a hole, wider than the one below, in the side of the frame and file it down thoroughly tso that more†. <***> and after the cloth has been rolled around this [the rod?], press it close to the loop and drive a pin through the hole in the side and from above, having pushed it through the loop.

(6) Thus, the roll of cloth remains bound together as it is held by it [the loop]. When the figures in the box must be covered, the doors being shut, draw the cord which is fastened to the pin and attached to the counterweight. So, all the coverings were made in this way, after they had been rolled together and placed aloft one after another in a row, each of them with <its own> loop and pin.

(7) ὅσον δ' ἂν τόπον καταλάβῃ τὰ εἰλημένα τῶν ὀθονίων, {ἐπὶ} τοσοῦτον ἀντιφράσσειν σανίσιν, ἵνα μὴ βλέπῃται. τὸ δὲ σανίδιον γίνεται ὑπέρθυρον {τῶν θυρῶν}. δεῖ δὲ ἐν αὐτῷ ποιῆσαι ἐπιστύλιον στρογγυλόγλυφον, ἵνα ἔχῃ λείαν ὄψιν.

5

XXVI

(1) Ταῦτα μὲν οὖν οὕτω γίνεται. κλεισθέντος δὲ καὶ ἀνοιχθέντος τοῦ πίνακος φαμεν μηδὲν φαίνεσθαι πλὴν ἀέρος καὶ θαλάσσης γεγραμμένων καὶ μετὰ ταῦτα παραπλεῖν τὰς ναῦς.

ποιήσομεν οὖν καὶ τὰ περὶ τὸν πλοῦν οὕτως. ἐξ ἑκατέρου μέρους τῶν θυρῶν παρὰ τοὺς στροφεῖς ἔξει ὁ πίναξ τόπους κενοὺς καταπεφραγμένους ἐκ τοῦ κατάπροσθεν ἰδίως ἀπεργαζομένους οἷον παραστάδων.

10

(2) ἐν δὲ τοῖς κενώμασι τούτοις ὑποπεφραγμένα σανίδια ἐπιτίθεται κανόνια ἔχοντα μέσα τετράγωνα ἰσόπλευρα εἰργασμένα καὶ ὀρθά, ὧν αἱ γωνίαι ἔσσονται καταδεδεμέναι. ἔσσονται δὲ ταῦτα ἐλάτινα, ἵνα μὴ λεπτὰ ὄντα διαστρέφονται. καὶ κάτωθεν μὲν αὐτῶν ἔσται προσκείμενα πυρηνίδια χαλκᾷ ἔντορνα, οἷς ὑποκείσονται ἐμπυελίδια, ἵνα

15

1 εἰλημένα Schmidt : εἰρημένα a : εἰλήματα Prou 2 ἐπὶ delevi ἀντιφράσσειν A^{cp} M : ἀντιφράσσειν G : <δεῖ> ἀντιφράσσειν vel tantum ἀντίφρασσε Schmidt dub. in app. crit. σανίσιν A^{cp} G M : σανιδίῳ Schmidt dub. in app. crit. : an σανιδώμασιν? 2-3 τὸ δὲ A G M : an τόδε <τὸ>? 3 τῶν θυρῶν delevi cum Schmidt (dub. in app. crit.) ἐν a : ἐπ' Prou 4 <καθάπερ> ἐπιστύλιον Schmidt dub. in app. crit. ἐπιστύλιον M^{pcsl} : ἐπιτύλιον A G M^{ac} T ἔχῃ A G : ἔχει M T λείαν a : ἡδεῖαν Prou 6 caput distinx. Schmidt οὖν om. A G καὶ <πάλιν> Schmidt dub. in app. crit. 6-7 ἀνοιχθέντος δὲ T 7 μηδὲν φαίνεσθαι R. Schöne : μὴ ἐμφαίνεσθαι a : μηδὲν ἐμφαίνεσθαι Egger, rec. Prou 10 οὕτως A G : οὕτω M 12 κατάπροσθεν Ta : κατὰ πρόσθεν A G M 13 ἰδίως A^{cp} G : ἰδίου M οἷον παραστάδων A^(ov cp) G M : οἷα παραστάδια Prou : an delenda ut glossema? 14 ἐν Ab Ac F Ld Pe^{pcsl} : ἐκ a Pe^{ac} ὑποπεφραγμένα A^{cp} G : ὑπογεγραμμένα M σανίδια T² : δια T¹ 17-18 διαστρέφονται A G : διαστρέφονται M T 18 αὐτῶν A^{cp} G : αὐτὸ M προσκείμενα A^{cp} M : προκείμενα G

(7) Screen off with boards the space that the rolls of cloth take up, in order that they may not be seen. The board serves as lintel {of the doors}. On this, it is necessary to make an architrave with rounded carvings, so that it may have a fine appearance.

xxvi (1) So, this takes place in this way. After the box has closed and opened, I say that nothing appears but painted sky and sea, and after this the ships sail by.

Thus, we will make the sailing scene as follows. On each side of the doors, near the pivots, the box will have shielded empty spaces, peculiarly finished over the outside like <those> of pilasters.

(2) Within these empty spaces are placed blocked boards, with bars in the middle constructed <so as to be> quadrangular, equilateral and upright, and the angles of which will be tied down. These will be of fir, in order not to warp because they are thin. Attached to the underside of them will be little bronze knobs turned on the lathe, with sock-

ὧσιν εὐστροφα, ἄνωθεν δὲ <***> στρογγύλα ἐργασθέντα
καὶ λεία.

(3) καὶ ἄνωθεν τρυπηθείσης τῆς πλευρᾶς τοῦ πλινθίου
διωσθήσεται, ὥστε μὴ σφίγγειν μήτε λίαν εὐλυτα εἶναι ὡς
στρέφεσθαι. τούτων γενομένων δεῖ χάρτην λαβόντα λε- 5
πτότατον τῶν βασιλικῶν καλουμένων ἀποτεμεῖν αὐτοῦ τὸ
μῆκος, ἥλικον ἂν περιέχῃ ὕψος τὸ τοῦ πίνακος ἔδαφος ἕως
τῶν ὀθονίων τῶν συνειλημένων καὶ ἀποτεμόντα τὸν ὀμ-
φαλὸν τοῦ χάρτου προσκολληῖσθαι αὐτὸν πρὸς τὸν κανόνα
τὸν ἐκ δεξιῶν τοῦ πίνακος, 10

(4) ὥστε ἀντὶ τοῦ ὀμφαλοῦ τὸν κανόνα προσκεκολληῖσθαι,
καὶ οὕτως ἐπιστρέφοντα τὸ ὑπερέχον τοῦ πίνακος περιει-
λεῖν τὸν χάρτην περὶ τὸν κανόνα κεκλεισμένου τοῦ πίνα-
κος. τοῦτο δὲ ἐπιστρέφεται, ἕως ἂν ἐπικαλυφθῇ ὅλον τὸ
ἔδαφος τοῦ πίνακος τῇ χάρτῃ. <οὐκ> ἔσται δὲ τοῦτο, ἕως 15
ἂν ἐπὶ τὸν τοῦ ἐτέρου κανόνος τόπον ἐγγίσης <***> πε-
πληρωκέναι τε καὶ οὕτως, ἐάν τι πλεονάζῃ, ἀποτέμνειν.

1 lacunam statui secutus Schmidt, qui <τὰ κανόνια ἔστω> dub. suppl. in app.
crit. : an <τὰ κανόνια ἔσται>? †στρογγύλα Schmidt 3 τρυπηθείσης hic
transposui : post πλινθίου A G M 4 διωσθήσεται Schmidt dub. in app. crit. :
διωθήσεται A G M μὴ A G M : an μήτε? λίαν A^{pc} : λείαν A^{ac} G M^{cp} T
εὐλυτα scripsi : εὐλυτον A^{cp} G M †ὥς Schmidt, qui τὸ dub. conl. in app.
crit. 5 χάρτην A G : γὰρ τὸν M 6-7 αὐτοῦ τὸ μῆκος A G M : αὐτὸ <κατὰ>
τὸ μῆκος Schmidt dub. in app. crit. 7 περιέχῃ A G : περιέχει M T τὸ ὕψος
a : transp. Schmidt ἔδαφος A^{cp} G M : ἐδάφους Prou ἕως Prou : ὡς a
8 ἀποτεμόντα Schmidt dub. in app. crit. : ἀποτεμόντων A G M : †ἀποτεμόν-
των Schmidt in textu : ἀποτεμόντας (sic) Prou 8-9 τῶν ὀμφαλῶν A^{accp}
12 καὶ Prou : ἢ a ἐπιστρέφοντα Mc : ὑποστρέφοντα a : ὑποστρεφόντας (sic)
Prou 13 κανόνα A G M : ἄξονα Prou 14-17 τοῦτο...ἀποτέμνειν del.
Schmidt, prob. Olivieri 15 <οὐκ> Schmidt dub. in app. crit. 16 ἐγγίσης A
G M : ἐγγίση Prou lacunam statuit Schmidt, qui <δεῖ δὲ τὸ τοῦ πίνακος
ἔδαφος μόνον ἕως τῶν ὀθονίων τῶν συνειλημένων τοῦ χάρτου, ὅταν τῇ
κανόνι ἐγγίσης> dub. suppl. in app. crit. : an <ὥστε τὸ ἔδαφος τοῦ πίνα-
κος>? 16-17 πεπληρωκέναι A G M : πεπληρώκη Prou 17 τε A G M : σε
Schmidt dub. in app. crit. ante καὶ graviter interpunx. Prou

ets below them to turn easily; at their upper ends <***> made round and smooth.

(3) When the side of the frame has been perforated at the top, they [the bars] will be driven through, so that they are neither caught nor too loose for turning. After these things have been done, one must take an exceptionally thin scroll of the so-called 'royal papyrus' and cut a length of it which may cover in height the backdrop of the box, up to the rolled-up cloths; and trimming off the roller of the scroll <one must> glue it [the scroll] onto the bar on the right-hand side of the box,

(4) so that the bar is glued on in place of the roller, and thus, by turning what sticks out from the box, one may wind the scroll around the bar when the box is closed. This is turned until the entire backdrop of the box has been covered by the scroll. This will <not> take place until you draw near to the region of the other bar <***> to have filled up and thus, if something is in excess, to trim it off.

(5) δεῖ δὲ ὑποκολληῖσαι ὑπὸ τὴν ἀρχὴν τοῦ χάρτου κανόνα σφόδρα λεπτὸν εἰργασμένον. ἔστω οὖν τὸ εἰλημένον παρὰ τὴν παραστάδα κεκρυμμένον, ὥστε ἀνεωγμένου τοῦ πίνακος μὴ ὀρᾶσθαι. ἐναρτῶ οὖν σπάρτους λεπτὰς εἰς τὸ κανόνιον τὸ πρὸς τῇ ἀρχῇ τοῦ χάρτου προσκεκολλημένον 5
<μίαν μὲν> κάτωθεν παρὰ τὸ παραστάδιον τοῦ πίνακος, ἄλλην δὲ ἄνωθεν παρὰ τὸ ὑπερθύριον καὶ ἀποδίδωμι εἰς τὸν ἄλλον κανόνα τὸν ἐν τοῖς εὐωνύμοις μέρεσιν.

(6) οὐκοῦν ἐὰν περιάγωμεν τὸν κανόνα, ἐπισπάσεται τὰς σπάρτους· ἐπειληθήσονται γὰρ αἱ σπάρτοι ἐξηρημέναι εἰς 10
τὴν ἀρχὴν τοῦ χάρτου, καὶ ἀκολουθήσει ὁ χάρτης. κεκλεισμένου οὖν τοῦ πίνακος ἕως τοσούτου ἐπιστρεφέσθω, ἕως ἂν ἐπικαλυφθῇ ὅλον τὸ ἔδαφος τῷ χάρτι. ἔσται δὲ οὗτος ἀέρα καὶ θάλασσαν ἔχων γεγραμμένα. ἵνα οὖν αὐτόματος παραγένηται ὁ χάρτης καὶ τῆς λείας βαρέως ἐπισπωμένης 15
ταχεῖα παραγωγὴ γίνηται πρὸς τὸ πολὺ πλῆθος τῶν πλοίων παραπλεῦσαι, δεῖ προμηχανήσασθαι ταῦτα.

(7) ἔστω γὰρ κατὰ τὸ ὀπισθεν μέρος φαινόμενος ὁ πίναξ ὁ ἀβγδ, καὶ τοῦ κανόνος, περὶ ὃν ἐλίσσεται ὁ χάρτης, τὸ 20
ὑπεράνω μέρος ἐξελίκτραν τετορνευμένην τὴν ζῆ
<ἐχέτω>, καὶ πρὸς τὸν πίνακα ἐπάνω τῶν ὑσπληγγίων καὶ τῶν ἀστερίσκων τῶν τὰ χέρια κινούντων ἀποσπᾶσας μι-

1 τὴν A^{cp} G^{pc} M : τὸ G^{ac} 2 τὸ εἰλημένον ad τοῦ χάρτου (1) referendum videtur 3 παραστάδα A G T^{ac} : παραστάδια M : παραστάδιον T^{pcsl} κε-
κρυμμένον M : κεκρυμένον A G T 4 ἐναρτῶ Ab Ea Lb Ta Tb^{2mg} : ἐν ἀρτῶ A
T : ἐναρτῶ M : ἐν αὐτῶ G Tb¹ 6 <μίαν μὲν> supplevi : <ἄλλην μὲν> Prou :
<τὴν μὲν> Schmidt dub. in app. crit. : <***> Schmidt in textu 9 οὐκοῦν A
M : οὐκοῦν G^{pcsl} : οὖν G^{ac} 10 ἐξηρημέναι Ta : ἐξητημέναι A G T : ἐξητη-
μέναι M 12 τοῦ om. M ἕως τοσούτου AM : ἕως τοσοῦτο G : ἐπὶ τοσοῦτο
Prou ἐπιστρεφέσθω <ὁ κανὼν> Schmidt dub. in app. crit. 13 ἂν om. M
ὅλον A^{cp} M : ὅλων G οὗτος A^{cp} G^{pc} M : οὕτως G^{ac} 14 θάλασσαν A^{cp} G M
: θαλάσσης T ἔχων A M^{cp} : ἔχων G γεγραμμένην A^{ac} 16 γίνηται A G :
γίνεται M T 17 πλοίων M^{cp} : πλείων A^{cp} G T 18 γὰρ om. A T κατὰ om.
G 19-20 an τὸ ὑπεράνω μέρος ante τοῦ κανόνος transponenda? 20 ἐξελί-
κτραν A^{pc} G : ἐξελίκτρου A^{ac} : ἐξελίκτρα M 21 <ἐχέτω> Schmidt dub. in
app. crit., lacunam statuens πρὸς a : παρὰ Schmidt dub. in app. crit.

(5) It is necessary to glue a bar worked very thin under the extremity of the scroll. So, let the roll be hidden near the doorjamb, so as not to be seen when the box is open. Therefore, I fasten thin cords to the bar glued to the extremity of the scroll, <one> below near the doorjamb of the box, another above near the lintel, and attach them to the other bar on the left.

(6) Then, if we turn the bar, it will pull the cords; for the cords attached to the extremity of the scroll will be wound up, and the scroll will follow them. So, when the box is closed, let it [the bar] rotate up to the point where the whole backdrop has been covered by means of the scroll. This will have sky and sea painted <on it>. These mechanisms must be engineered in advance, in order that the scroll may move by itself and, despite the counterweight pulling it slowly, its sliding may occur rapidly, so that a great number of ships sail by.

(7) Let there be the box seen from behind, $\overline{\alpha\beta\gamma\delta}$, and <let> the upper part of the bar, around which the scroll is rolled, <have> a lathe-turned bobbin, $\overline{\zeta\eta}$; against the box, above the *hysplēngia* and after I have drawn it a little bit away from the starwheels that move the arms, I place a drum $\overline{\theta\kappa}$.

Fig. 30

κρὸν παρατίθημι τύμπανον τὸ $\overline{\theta\kappa}$. ἐχέτω δὲ τὸ τύμπανον
κατὰ κορυφὴν {μέρος} κύκλῳ τετορνευμένον τροχίλον.

(8) καὶ περὶ τὸν ἄξονα τοῦ τυμπάνου ἄλλον περιτίθημι
ἄξονα μικρὸν προσαραρότα τῷ ἄξονι τὸν $\overline{\mu}$, ὅπως {συμ-
φυῇ ὡς} ἅμα στραφήσεται <τῷ> μείζονι τυμπάνῳ. περιει-
λήσας οὖν σπάρτον περὶ τὴν $\overline{\eta\zeta}$ ἐξελίκτραν, ὅση μέλλει
ἐξελίσσειν τὸν χάρτην, †δὲν† ἀποδίδωμι <***> περὶ <τὸν>
ἕτερον τροχίλον <***> τῷ πρώτῳ τυμπάνῳ τὸν $\overline{\mu}$ περι-
ειλῶ τὴν εἰς τὴν λείαν ἀποδοδομένην σπάρτον. ἔστω δὲ ἡ
 $\overline{\nu}$.

(9) δῆλον οὖν ὅτι μικρὸν τῆς σπάρτου ἐλκυσθείσης ὑπὸ
τῆς λείας πολὺ μέρος τοῦ χάρτου καὶ ταχὺ ἀπειληθήσεται.
ἄξων δέ, ἐν ᾧ ὀχεῖται τὸ τύμπανον, <ἔστω> ὁ $\overline{\theta\zeta}$. χρὴ δὲ
τοὺς ἀστερίσκους καὶ τὸ τύμπανον ἀνεμποδίστως κινεῖ-
σθαι.

1 παρατίθημι Schmidt dub. in app. crit. : περιτίθημι A G M 2 ante κατὰ
lacunam statuit Schmidt κορυφὴν Ab^{pc} Ac Ld : κρυφὴν Ab^{ac} : κουρὰν a,
quo recepto <κατὰ τὸ> ante κατὰ dub. suppl. Schmidt in app. crit. : κρόταφον
codex a Baldi adhibitus μέρος delevi ut glossema lacunosum (i.e. <εἰς τὸ
ἄνω> μέρος vel sim.) τροχίλον Ld : τρόχιλον A G M : ἄξονα Schmidt dub.
in app. crit. 4 ἄξονα a : τρόχιλον (sic) Schmidt dub. in app. crit. προσα-
ραρότα A^{cp} G : προαραρότα T : προαραρώτα τὰ M $\overline{\mu}$ Schmidt : μὲν a
4-5 συμφυῇ ὡς ut glossema ad προσαραρότα delevi cum Schmidt (dub. in
app. crit.), qui etiam συμφυῆς ὡς conl. : †συμφυῇ ὡς Schmidt in textu
5 <τῷ> Schmidt dub. in app. crit. 6 $\overline{\eta\zeta}$ A M : $\overline{\epsilon\zeta}$ G : an $\overline{\zeta\eta}$? 7 cruces posui
secutus Schmidt, qui ἦν dub. conl. in app. crit. : an εἰς τὸ τύμπανον?
lacunam statuit Schmidt, qui <εἰς τὸ τύμπανον τὸ $\overline{\theta\kappa}$ > dub. suppl. in app. crit.
: an <καὶ>? <τὸν> Schmidt dub. in app. crit. 8 τροχίλον Ld : τρόχιλον A
G M : an ἄξονα? lacunam statuit Schmidt, qui <ἅμα στρεφόμενον> dub.
suppl. in app. crit. τὸν A^{cp} G : τῷ M $\overline{\mu}$ A G : $\overline{\mu\varsigma}$ M T 9 τὴν λείαν A^{cp} G
M^{pc} : τὴν μίαν λείαν M^{accp} 11 ἐλκυσθείσης Prou : ἐκχυθείσης A^{cp} G T :
ἐκλυθείσης M 12 πολὺ A G : πολλῷ M μέρος A^{ac} : μέρει A^{pc} (ut videtur) G M
T ἀπειληθήσεται Schmidt dub. in app. crit. : ἐπειληθήσεται A G M, quo
recepto post hoc verbum non interpunx. Prou 13 ἄξων δέ A G M : ἄξονι $\overline{\theta\kappa}$
Prou ἐν a : σὺν Schmidt dub. in app. crit. ὀχεῖται scripsi : ἔχει a : τρέχει
Schmidt dub. in app. crit. <ἔστω> Schmidt dub. in app. crit., lacunam
statuens ὁ scripsi : τὸ A G M $\overline{\theta\zeta}$ Schmidt dub. in app. crit. : $\overline{\xi}$ Tb : $\overline{\nu\zeta}$ a

Let the drum have at its vertex {part} a pulley turned on the lathe all around.

(8) Around the axle of the drum, I set another axle, small and firmly fitted to the axle, $\bar{\mu}$, so that {attached like} it will rotate together with <the> bigger drum. So, after winding a cord around the bobbin $\bar{\eta}\zeta$, as much as is expected to unroll the scroll, †which† I pass <***> I wind the cord going to the counterweight around <the> other pulley $\bar{\mu}$ <***> with the first drum; let it [the counterweight] be \bar{v} .

(9) So, it is clear that, when the cord has been pulled by the counterweight just a little, a large portion of the scroll will be unwound, and swiftly. <Let there be> an axle, on which revolves the drum, $\bar{o}\xi$. The starwheels and the drum must move unhampered.

(1) Ὁ μὲν οὖν παράπλους οὕτω γίνεται. οἱ δὲ δελφῖνες ὅτε μὲν καταδύσσονται, ὅτε δὲ φανήσονται κατὰ τὸν ὑπογεγραμμένον τρόπον. ἐκ τῆς κάτω πλευρᾶς τοῦ πλινθίου τῆς πρὸς τὸ θωράκιον ἡρμοσμένης μικρὸν ἀπὸ τῶν στροφέων ἀπολιπὼν ἐποίησα ἐκκοπὰς στενὰς ὥσεί γομφωτηρίων, 5 ὥστε διαφαίνειν εἰς τὸ θωράκιον κάτω.

(2) καταλαβὼν σανίδα ἔγραψα τὰ δελφινάρια, ἡλίκα βούλομαι, καὶ περιέτεμον καὶ περιερρίνησα τὴν ἐκτὸς γραμμὴν. ἔστω δὲ ἄξονιον ὑπὸ τὰ στέρνα τοῦ δελφιναρίου, ἐν ᾧ ἔπηξα περόνην σιδηρᾶν. καὶ <***> εἰς τὰ στέρνα τοῦ 10 δελφιναρίου. ἔστω εἰς τὴν ἐκκοπὴν ὀχούμενος ἐξ ἑνὸς μέρους τροχίλος καθάπερ τὸ ὑπογεγραμμένον. ἡ δὲ ἐκκοπὴ ἢ ἐκ τῆς πλευρᾶς <ἔστω> ἢ $\overline{a\beta}$, ἄξων δὲ ὁ $\overline{\gamma\delta}$, τροχίλος δὲ ὁ $\overline{e\zeta}$.

(3) τρυπῶ οὖν τὸν ἄξονα κατὰ τὴν ἐκκοπὴν <κατὰ> τὸ $\overline{\theta}$ 15 καὶ ἐνέπηξα τὴν περόνην τοῦ δελφιναρίου. οὐκοῦν ἕαν τις περιάγῃ τὸν τροχίλον τῇ χειρί, ὅτε μὲν καταδύσεται ὁ δελφινίσκος κάτω διὰ τῆς ἐκκοπῆς εἰς τὸ θωράκιον, ὅτε δὲ ἀναδύσεται ἐν τῷ πίνακι.

(4) ἵνα οὖν αὐτόματον <τοῦτο> γένηται, σπάρτον ἀπαγκυλώσας περιτίθημι περὶ τὸν τύλον τὸν ἐνόντα ἐν τῷ τρο- 20

1 ὁ om. G οὖν om. M T 5 ἐποίησα Haase : ἐποίησε Ab Ac Ld Pa : ἐποίησεν a ἐκκοπὰς Bc Ea Lb O^{pcl} : ἐκοπὰς AG O^{ac} : ἐκ ποὰς T : ἐκπνοὰς M στενὰς Ea Lb : στεγνὰς a an ὥσεί γομφωτηρίων delenda ut glossema? 7 καταλαβὼν a : καὶ λαβὼν Schmidt dub. in app. crit. σανίδα AG T : σανίδα M 8 περιερρίνησα A^{ac} T^{ac} : περιερρίνισα A^{pcl} G M T^{pcl} : an ἐρρίνησα? 10 ἔπηξα M : ἔσπηξα AG T : ἐνέπηξα Schmidt dub. in app. crit. σιδηρᾶν AG : σιδηροῦν M ante καὶ graviter interpunx. AGM et ed. princ. : non interpunx. Prou et Schmidt lacunam statuit Schmidt, qui <ἐμπεπηγυῖαν> dub. suppl. in app. crit. : an <ταύτην ἐνέπηξα> vel <ταύτην ἐνήρμοσα>? 11 ὀχούμενος Ta^{pcl} : ὀχούμενον AGM^φ Ta^{ac} : †ὀχούμενον Schmidt 12 τρόχιον Schmidt dub. in app. crit. 13 <ἔστω> Schmidt dub. in app. crit. 15 <κατὰ> Schmidt 16 δελφιναρίου <εἰς τὸ τοῦ ἄξονος τρύπημα> Schmidt dub. in app. crit. 17 καταδύσεται GMT : καδύσεται A 20 <τοῦτο> Schmidt γένηται AGM : an γίνηται?

xxvii (1) So, the coasting voyage takes place in this way. The dolphins will now plunge, now come into view in the way described below. On the lower side of the frame, which is fitted to the enclosure, having left a small interval from the pivots, I made narrow notches like <those> for tenons, in such a way that they allow light through to the enclosure below.

(2) After taking a board, I drew the dolphins of the size I want, cut around their outlines and filed them down. Under the dolphin's chest let there be an axle, in which I fixed an iron pin; and <***> to the dolphin's chest. Let there be a pulley inside the notch driving on one side, as illustrated below. <Let there be> a notch on the side, $\overline{\alpha\beta}$, an axle, $\overline{\gamma\delta}$, and a pulley, $\overline{\epsilon\zeta}$.

Fig. 31

(3) Thus, I pierce the axle with a hole <at> $\overline{\theta}$ opposite the notch and fixed the dolphin's pin <in it>. Therefore, if someone turns the pulley by hand, the dolphin will dive down through the notch into the enclosure at one time, and come up inside the box at the next.

(4) So, in order for <this> to happen automatically, I make a loop in a cord, put it around the knob which is on the pulley, $\overline{\zeta}$, and after winding it around the pulley, I attach it

χίλῳ τὸν ζ̄ καὶ περιελίξας τὸν τροχίλον ἀποδίδωμι εἰς τὴν
 λείαν. ὁ δὲ δελφινίσκος οὕτως ἐμπεπηγὼς ἔσται εἰς τὸν
 ἄξονα ὥς <***> ἐφ' οὗ τὸ κ̄, πρὸς ὀρθὰς ὧν τῷ ἄξονι, ὁ
 δὲ γδ̄ ἄξων πρὸς ὀρθὰς τῷ θωρακίῳ.

- XXVIII** **(1)** Πέρας οὖν ἔχοντος τοῦ παράπλου κλεισθήσονται πάλιν 5
 αἱ θύραι, καὶ ἡ σπάρτος ἐλκυσθεῖσα ἐκσπάσει τὸ περόνιον
 καὶ καταρρίψει τὸ ὀθόνιον, ἐν ᾧ ἔσται ὁ Ναύπλιος γε-
 γραμμένος ὁ τὸν πυρσὸν ἡρκῶς καὶ ἡ Ἀθηνᾶ. καὶ ἀνοι-
 χθέντος τοῦ πίνακος αἱ μὲν νῆες οὐ φαίνονται, τὰ δὲ προ-
 ειρημένα. δεήσει δὲ καὶ τὸν πυρσὸν εὐθὺς ἀνακαίεσθαι. 10
- (2)** ποιήσομεν οὖν καὶ τὰ κατὰ τὸν πυρσὸν οὕτως ἔσται
 ἡμῖν ἐπὶ τοῦ ἐπιστυλίου καὶ τῶν τριγλύφων σανὺς ἐπισκο-
 τοῦσα δι' ὅλου τοῦ πίνακος, ἥτις ἐπικαλύψει τὴν τε ἐξελί-
 κτραν τὴν τὸν παράπλου ἀγούσαν καὶ τὴν τοῦ πυρὸς
 πραγματείαν καὶ τὴν τῆς μηχανῆς ἔπαρσιν, ἵνα μηδὲν τῶν 15
 προειρημένων εἰς τὸ κατάπροσθεν μέρος τοῦ πίνακος φαί-
 νηται.
- (3)** ὅπως δὲ μὴ ἀλόγως ἡ σανὺς ἐπικειμένη <ῆ>, ἀετὸς
 προστίθεται αὐτῇ καθάπερ δὴ ναῖσκῳ· τὰ δὲ ἀπολειπόμενα

1 περιελίξας <περὶ> Schmidt dub. in app. crit. 2 τὸν <γδ̄> ἄξονα Schmidt
 dub. in app. crit. 3 lacunam statuit Schmidt, qui <ὁ τροχίλος> (sic) dub.
 suppl. in app. crit. : an <ὁ ἄξων εἰς τὸ θωράκιον,>? τὸ Schmidt dub. in app.
 crit. : ὁ A G M 4 <ἔστω> τῷ Schmidt dub. in app. crit. 6 ἐκσπάσει A G M
 T² : καὶ σπάσει T¹ 7-8 an γεγραμμένος post ἔσται transponendum? 8 ἡρ-
 κῶς A G M : ἡρκῶς Pc, rec. Prou (ἡρ-) 9 οὐ φαίνονται A G : φαίνονται M :
 ἐφαίνονται T : ἐμφαίνονται Ta : οὐκέτι φαίνονται Schmidt dub. in app. crit.
 10 καὶ A^{cp} M^{cp} : ἐκ G τὸν om. M 11 τὰ om. M 12 ἐπιστυλίου Prou :
 ἐπιστύλου A G : στύλου M T 14 ἄγούσαν A^{cp} G M : αἰούσαν Pc, rec. ed.
 princ. πυρὸς A^{cp} G M^{cp} : πυρσοῦ Schmidt dub. in app. crit. 15 ἔπαρσιν
 A^{cp} M^{cp} : ἔπαρσιν G : ἄρσιν codex a Baldi adhibitus 16 κατάπροσθεν M :
 καταπρόσθεν G : κατὰ πρόσθεν A T : κάτω πρόσθεν Prou 18 ἐπικειμένη M
 : ἐπιμήκειμένη A T : ἐπιμήκει κειμένη G : ἐπὶ* μὴ κειμένη ed. princ. (*f. ῆ' in mg.)
 : ἐπιμένη κειμένη Haase : ἐφ' ἧ κεῖται Prou, postea non interpungens <ῆ>
 Schmidt : <ῆ> ἐπικειμένη R. Schöne <ὁ> ἀετὸς Prou, postea leviter
 interpungens 19 προστίθεται G M : πρὸς τίθεται A : προστίθεται Prou
 αὐτῇ A G : τῇ M T ἀπολειπόμενα A^{cp} G : ἀπολιπόμενα M T

to the counterweight. The dolphin will thus be fixed to the axle like <***> at $\bar{\kappa}$, being at right angles to the axle, and the axle $\bar{\gamma}\delta$ at right angles to the enclosure.

- xxviii** **(1)** So, when the voyage comes to an end, the doors will close again, and the cord, having been pulled tight, will draw out the pin and bring down the cloth, on which will be painted Nauplius, holding up the torch, and Athena. Once the box has opened, the ships are not in sight, but what has been said before. It will also be necessary for the torch to blaze up promptly.
- (2)** Therefore, we will make the mechanisms for the torch as follows: on the architrave and triglyphs we will have a board overshadowing the whole box, which will conceal the bobbin that triggers the voyage, the fire-lighting device and the lifting of the machine, so that none of the above may be seen from the front of the box;
- (3)** but in order for the board not <to be> set in place without apparent reason, a pediment is added to it just like

ἐκατέρωθεν πτερύγια τῆς σανίδος ἐπιφύρεται μέλανι ἢ ἄερν· τίθεται δὲ ἐχομένη τῆς ἐξελίκτρας ἢ μηχανῆς. τῆς δὲ μηχανῆς ἐκ τοῦ ἄλλου μέρους ἢ τοῦ πυρσοῦ γίνεται κατασκευὴ τοιαύτη οὕσα. ἐκ λεπίδων χαλκῶν δεῖ ποιῆσαι καθάπερ κιβωτάριον πῶμα μὴ ἔχον, ἀλλὰ ἀχανές.

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(4) τοῦτο δὲ δεῖ στήσαι ὀρθὸν ὀπίσω τῆς σανίδος τῆς ἐπικαλυπτούσης καὶ καθηλῶσαι πρὸς τὴν πλευρὰν τοῦ πλινθίου. ἐχέτω δὲ τὸ μὲν ἔδαφος τὸ κιβωτάριον πρὸς τῇ σανίδι, τὸ δὲ χάσμα ἔξω βλέπον τῆς σανίδος. ἐκ δὲ τῆς ἄνω πλευρᾶς τοῦ κιβωταρίου ἐκκεκόφθω ὀπὴ διαφαίνουσα ὥσεί θυρίς, ὥστε ὅταν λύχνος καιόμενος τεθῇ εἰς τὸ κιβωτάριον, τὸ τῆς φλογὸς αὐτοῦ διήκειν ἄκρον εἰς τὸ ἄνω μέρος τοῦ κιβωταρίου διὰ τῆς ὀπῆς. τούτου δὲ ὑπάρχοντος, ὁ λύχνος ὑποκείσθω καιόμενος.

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(5) ἄλλω δὲ λεπιδίῳ χαλκῷ τριγώνῳ καταπωμάζομεν τὴν ὀπὴν, ὥστε ἀποκεκλείσθαι τὴν φλόγα. ἐπάνω δὲ τοῦ κιβωταρίου καὶ τῆς πεπωμασμένης λεπίδος ἐπιτίθημι ξύσματα τεκτονικὰ ξηρότατα. οὐκοῦν ὅταν ἀποσπᾶσω τὸ λεπίδιον τὸ πεπωμακὸς τὴν ὀπὴν, ἡ φλόξ τοῦ λύχνου ἄψεται τῶν ξυσμάτων, καὶ εὐθὺς ἀνακαυθήσεται. πρὶν δὲ τὰ ξύσματα καυθῆναι, οὐ βλέπεται ἡ τοῦ λύχνου φλόξ κεκρυμμένη ἐν τῷ κιβωταρίῳ.

15

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(6) καὶ γὰρ ξύλινον ἐπιούριον ἔξει, ἐὰν βουλώμεθα τελείως πάντοθεν πωμάσαντες ἄορατον ποιῆσαι τὴν φλόγα.

1 ἐπιφύρεται Schmidt dub. in app. crit. : ἐπιφύεται a : ἐπιχρίεται R. Schöne
2-3 ἀν ἐκ δὲ τοῦ ἄλλου μέρους τῆς μηχανῆς? 9 βλέπον AG MT^{ac} : βλέπων
T^{pcsl} 10 κιβωταρίου T^{mg} : κιβωταρίου M : κιβωτηρίου vel κιβωτέρου A^{cp}
G^{cp} : κιβώτρου T (in textu) : κιβωτοῦ EaFLb 11 εἰς om. MT 13 τούτου AG
: τοῦτο MT δὲ <οὕτως> Schmidt dub. in app. crit. 13-14 post ὑπάρχον-
τος leviter interpunx. AG et Prou : non interpunx. Med. princ. et Schmidt
15 καταπωμάζομεν M^{cp} : κατὰ πωμάζομεν AT : κατὰ πωματίζομεν G
20 εὐθὺς <ταῦτα> Schmidt dub. in app. crit. 23-4 αὐτ καὶ γὰρ... φλόγα
delere αὐτ ἐπιούριον in κλειθρίον mutare dub. proposuit Schmidt in app. crit.
γὰρ A^{cp} G : τὸ MT ἐπιούριον AMT : ἐπίουρον G

to a shrine. The remaining wings on either side of the board are painted black or the colour of the sky; the machine is positioned next to the bobbin. On the other side of the machine is the torch, which is constructed as follows. It is necessary to make a kind of small chest out of bronze sheets, with no lid, but wide open.

(4) This must be stood upright behind the covering board and nailed down onto the side of the frame. Let the small chest have its bottom against the board, and its opening looking out from the board. Let an aperture be cut out of the upper side of the small chest, letting light through just like a little window, so that, when a lamp has been lit and put into the small chest, the tip of its flame reaches into the upper part of the small chest through the aperture. As it stands, let the lighted lamp be set beneath.

(5) We cap the aperture with another triangular bronze plate, so as to close off the flame. Above the small chest and the capping plate, I place especially dry woodwork shavings. Therefore, when I draw away the plate that covers the aperture, the flame of the lamp will set the shavings on fire, and they will immediately flare up. Until the shavings catch fire, the flame of the lamp is not seen, being hidden in the small chest;

(6) for it will have a little wooden peg, if we want to make the flame invisible by capping it off completely from all

ἵνα δὲ ἀσφαλῶς μένη ὁ λύχνος ἐν τῷ κιβωταρίῳ, περόνιον ἔστω ὑπερέχον ἐκ τοῦ κάτω μέρους. ὁ δὲ λύχνος ἔστω τῶν εἰς τοὺς λαμπτήρας ἐμβαλλομένων καὶ περιτιθεμένων περὶ περόνην. ἵνα οὖν περὶ τὸν καθήκοντα καιρὸν αὐτόματον ἀνοιχθῇ τὸ λεπίδιον, παρατίθημι ἀξόνιον ἀπέχον ἀπὸ τοῦ πυρός.

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(7) ἐκ δὲ τῆς λεπίδος ἀλυσείδιον ἀνάψας ἐξέδησα εἰς τὸ ἀξόνιον, ὅπως ὅταν ἐπιστραφῇ τὸ ἀξόνιον, περιειληθῇ τὸ ἀλυσείδιον καὶ ἐπισπάσῃται τὸ λεπίδιον. ἐπιστρέψει δὲ ὁμοίως τὸ ἀξόνιον σπάρτος ἐκ τῆς λείας περὶ τύλον. {ἔστω δὲ τὸ λεπίδιον τὸ $\bar{\alpha}$, ἀλυσείδιον δὲ περὶ τοὺς τύλους τὸ $\bar{\beta}$, ἄξων δὲ τὸ $\bar{\gamma}$, τύλος δὲ τὸ $\bar{\delta}$, σπάρτος δὲ ἡ περὶ τὸν τύλον τὸ $\bar{\epsilon}$.}

10

XXIX

(1) Φανέντων δὲ τῶν προειρημένων καὶ τοῦ πυρὸς ἀνακαυθέντος, κλεισθήσεται πάλιν ὁ πίναξ. καὶ ἐκσπάσασα ἡ σπάρτος τὴν περόνην καταρρίψει τὸ ὀθόνιον, ἐν ᾧ ἔσται γεγραμμένη ἡ ναυαγία τῶν νηῶν καὶ τὸ τοῦ Αἴαντος ζῶδιον νηρόμενον. ἐν δὲ τῷ πίνακι φανήσεται ἡ Ἀθηνᾶ. ἔσται δὲ ἡ βάσις αὐτῆς ἔχουσα ἐν τοῖς προσήκουσι τόποις τύλους.

15

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(2) καὶ μία μὲν σπάρτος ἐγερεῖ αὐτὴν ἐπισπασαμένη ἐκ τοῦ ὀπισθεν μέρους τοῦ ἰσχαρίου κατὰ τὸ σήκωμα αὐτῆς· ἀποσπασθείσης δὲ ταύτης ἄλλη περικειμένη περὶ τὸ θωράκιον περιᾶξει αὐτήν, ἕως ἂν ἔλθῃ ἐπὶ τὸν αὐτὸν τόπον,

4 περόνην A G M : περόνας Schmidt dub. in app. crit. 5 <μικρόν> ἀπέχον ἀπὸ τοῦ πυρὸς Schmidt dub. in app. crit. : an ἀπέχον ἀπὸ τοῦ πυρὸς <ίκανόν> vel <βραχύ> ἀπέχον A G M : ἀπέχοντα T 7 ἀλύσει M ἀνάψας Pg : ἐνάψας A G : ἐν ἄψας M ἐξέδησα A G M : ἐξέδυσα T 10 <περιτεθείσα> περὶ Schmidt dub. in app. crit. 11-13 ἔστω...ε̄ delevi περὶ τοὺς τύλους del. Schmidt dub. in app. crit. 14 caput distinx. Haase πυρὸς A G M : πυρσοῦ Prou dub. 16 καταρρίψει Schmidt dub. in app. crit. : ρίψει A G M 17 γεγραμμένη R. Schöne : καταγεγραμμένη A G M νηῶν a : νεῶν Prou 21 ἐπισπασαμένη A^{op} G : ἐπισπαμένη M : ἐπισπωμένη Ab Ac Ld 23 ἀποσπασθείσης Schmidt dub. in app. crit. : ἀποσπασθείσης A G M

sides. In order that the lamp may remain steady inside the small chest, let there be a pin projecting from the underside. Let the lamp be <one> of those placed in lanterns and set around a pin. So, in order for the plate to open by itself at the proper time, I place an axle at a distance from the flame.

Fig. 32

(7) After fastening a thin chain to the plate, I bound it to the axle, so that, when the axle rotates, the thin chain may be wound and may draw the plate. A cord <attached> to the counterweight <and looped> around a knob will likewise turn the axle. {Let there be the plate, $\bar{\alpha}$, a chain around the knobs, $\bar{\beta}$, an axle, $\bar{\gamma}$, a knob, $\bar{\delta}$, and the cord around the knob, $\bar{\varepsilon}$.}

xxix (1) After the previously mentioned effects have been seen and fire has blazed up, the box will close again. When the cord has drawn out the pin, it will bring down the cloth, on which will be painted the wreck of the ships and the figure of Ajax swimming. Athena will appear in the box. Her base will have knobs in appropriate places.

(2) One cord will raise her up by pulling from behind the joint [mechanical element] in accordance with her counterbalance. When this has been released, another <cord> lying around the enclosure will turn her around, until she reaches the same place from which she set off. When this

ὅθεν ἐξήλθεν· ἀποσχασθείσης δὲ ταύτης ἄλλη σπάρτος ἐπισπάσεται ἐκ τοῦ ὀπισθεν μέρους τοῦ ἰσχαρίου καὶ οὕτω κατακλινεῖ τὴν Ἀθηνᾶν.

- xxx** **(1)** Λοιπὸν δέ ἐστιν ἡμῖν διηγήσασθαι, τίνι τρόπῳ ὃ τε κεραυνὸς ἐν τῷ πίνακι πεσεῖται καὶ τὸ τοῦ Αἴαντος ζώδιον ἀφανισθῇσεται. γίνεται οὖν καὶ ταῦτα, καθάπερ μέλλομεν ἐξηγεῖσθαι κατὰ μέρος. ὅπου τὸ ἔδαφος τοῦ πίνακος, ἔσται γεγραμμένον τὸ ζώδιον· κατ' αὐτὸ δὲ ἔστω ἐκκοπή ἐν <τε> τῇ ἄνω πλευρᾷ τοῦ πλινθίου πεποιημένη καὶ ἐν τῇ κάτω, καθάπερ καὶ ἐπὶ τῶν δελφίνων ἐδηλώσαμεν. 5 10
- (2)** κατατείνονται οὖν ἐκ τῆς ἄνωθεν πλευρᾶς τῆς ἐκκοπῆς χορδαὶ δύο λεπτόταται τῶν εἰς τὰς σαμβύκας ἐμβαλλομένων ἕως κάτω εἰς τὸ θωράκιον διὰ τῆς ἄνω οὔσης ἐκκοπῆς. ἵνα δὲ ἐν τῷ ναίσκῳ ὥσι τεταμέναι, καθάπτονται εἰς κολλάβους δύο ἐκ τοῦ ἄνωθεν μέρους, ἵνα ἐπιστρεφομένων τῶν κολλάβων τὴν τάσιν ἔχωσιν. 15
- (3)** ἐγερθὲν δὲ σανίδιον λεπτὸν καὶ ὑπόμηκες, ὥστε χωρεῖν αὐτὸ διὰ τῶν ἐκκοπῶν εὐκόπως καὶ σταθὲν ἐκ τοῦ ὑπερθύρου μὴ ὑπερέχειν αὐτὸ τὸ ὑπέρθυρον εἰς τὸν πίνακα <***>. τρυπηθὲν δὲ δυσὶ τρυπήμασι κατὰ μῆκος περιλαμ- 20

1 ἀποσχασθείσης AGMF^(in textu) : ἀποσπασθείσης AbAcF^(dub. in mg.) Ld
2 ὀπισθεν a : ἔμπροσθεν Schmidt secutus R. Schöne **3** ἀθηνᾶ G^{pc} **4** caput
 distinx. Schmidt ἡμῖν A^{cp}G : ἑμοὶ M : ἡ μὲν T ὃ τε A : ὅτε GM **7** ἔδα-
 φος GM : ἔφος A^{cp} : ἔφο T **8** post τὸ lacunam statuit Schmidt, qui <τοῦ
 Αἴαντος> dub. suppl. in app. crit. αὐτὸ Haase : αὐτὸν a δὲ A^{cp}G : δ' M
9 <τε> Schmidt dub. in app. crit. **12** σαμβύκας Prou : ἄμβυκας a Aa^{ac}Ph^(in textu) : ἄμπυκας Aa^{pcsl}Ph^(dub. in mg.) **13** θωράκιον GM : ῥάκιον AT
13-14 ἐκκοπῆς <καὶ τῆς κάτω> Schmidt dub. in app. crit. **14** ἐν τῷ ναίσκῳ
 AGM : ἐν τῷ πίνακι Schmidt dub. in app. crit. : an ἐπάνω τοῦ νεανίσκου?
 τεταμέναι R. Schöne : τεταγμέναι a **15** δύο Schmidt : β Ph^(dub. in mg.) : α a
16 τάσιν R. Schöne : στάσιν a **17** ἐγερθὲν A^{cp}GM : ἐργασθὲν Prou δὲ
 <ἔστω> Schmidt dub. in app. crit. **18** αὐτὸ AM : αὐτῶν G ἐκ <τοῦ ἄνω
 μέρους> τοῦ ὑπερθύρου Schmidt dub. in app. crit. **20** lacunam statui ante
 τρυπηθὲν leviter interpunx. Prou **20-108.1** περιλαμβάνει a : περιλαμβάνειν
 Prou

has been released, another cord will pull from behind the joint and thus lay Athena down.

- xxx** **(1)** It remains for us to detail how the bolt of lightning will fall inside the box and the figurine of Ajax will vanish. So, these effects take place just as I am going to spell them out one by one. The figurine will be painted where the back-drop of the box <is>. Across from it, let there be a notch made <both> in the upper side of the frame and in the lower one, just as I have shown for the dolphins.
- (2)** So, two extremely thin gut strings of the kind placed on sambucas are stretched tight from the upper side of the notch down into the enclosure through the notch above. In order for them to be stretched taut inside the shrine, they are fastened to two pegs on high, so as to obtain tension when the pegs are turned.
- (3)** Once a thin and longish board has been raised, so that it passes through the notches easily, and once it has been made to stand beyond the lintel, so as not to jut out from the lintel itself into the box <***>. Having been pierced lengthwise with two holes, it encases the strings by means

βάνει τὰς χορδὰς ἐπιούροις· προσκολλᾶται δὲ καὶ ὄπισθεν τοῦ σανιδίου {τὸ} μολύβδιον λεπτόν, ὅπως βάρος ἴσχη.

(4) εἰάν οὖν ἄγωμεν τῇ χειρὶ τὸ σανίδιον ἄνω διὰ τῆς ἐκκοπῆς, ἀποπесεῖται διὰ τοῦ πίνακος φερόμενον ὀρθόν, ὥς ἂν περὶ τὰς χορδὰς περικείμενον. αἱ μὲν οὖν χορδαὶ μέλανι 5 μολύνονται, ἵνα μὴ δῆλαι ᾖσι· τὸ δὲ ὑποσανίδιον ἐκ μὲν τοῦ κάτω μέρους χρυσοῦται καὶ λειοῦται ὥς μάλιστα. ἐκ δὲ τοῦ ἄνωθεν ὑπογράφεται τι πυροειδές, ὥς τὴν τοῦ κεραυνοῦ φαντασίαν ποιεῖν.

(5) φέρεται δὲ τοῦτο, ὅταν ἀφεθῇ, κατὰ μέσον τὸ ζώδιον, 10 ὥς τεταμέναι εἰσὶν αἱ χορδαί. τοῦτο δὲ ἄνω μένει περονίῳ κρατούμενον, καθάπερ καὶ τὰ ὀθόνια, ὅπως ὅταν καθῆκον ᾦ, ἡ σπάρτος ἐπισπασαμένη τὸ περόνιον ρίψῃ τὸν κεραυ- νόν. τὸ ζώδιον πεσόντος τοῦ κεραυνοῦ ἀφανίζεται οὕτως· 15 ἔστιν ἕτερον ὀθόνιον πεποιημένον καθάπερ καὶ τὰ ἄλλα τὰ ἐπικαλύπτοντα, μικρὸν δέ, ὥς αὐτὸ τὸ ζώδιον ἐπικαλύ- ψηται τὸ ὀθόνιον. ἐν δὲ τούτῳ γέγραπται θάλασσα ὁμοία τῇ περιεχούσῃ τὸ ζώδιον καὶ τὰ κύματα.

1 ἐπιούροις <προσηγυλωμένας> Schmidt dub. in app. crit. 2 τὸ delevi : τι Schmidt dub. in app. crit. μολίβδιον M : correxi : μολυβίδιον T : μολιβίδιον A G : †μολιβίδιον Schmidt, qui <πλατυσμάτιον> μολύβδιον dub. conl. in app. crit. 3-4 διὰ τῆς ἄνω ἐκκοπῆς Schmidt dub. in app. crit. 4 ἀποπесεῖται Prou : ἀποπέση a : †ἀποπέση Schmidt, qui <οὐ μὴ οὐκ> ante hoc verbum dub. suppl. in app. crit. 7 καὶ λειοῦται om. T¹ : add. T² 8 ὑπογράφεται A G M : ἀπογράφεται Prou πυροειδές A^{op} G : πυροειδοῦς M 10 μέσον τὸ A^{op} M : μέ|σὸ G^{pc} : μέ|τὸ G^{ac} 11 τεταμέναι Schmidt : τεταγμέναι a μένει R. Schöne : βλέπει a 12 καθῆκον G M : καθίκον A^{op} T 13 ἡ A G M : ἡν T ἐπισπασαμένη M^{op} : ἐπιασμένη A^{op} G T περόνιον G M : περόριον A T ρίψῃ A G : ρίψει M 14 τὸ <δ' Αἴαντος> ζώδιον (sic) Prou : τὸ <δὲ> Schmidt dub. in app. crit. 16-17 ἐπικαλύπτεται Prou : ἐπικαλύπεται A^{op} G^{op} M 17 τούτῳ G : του A : τοῦ M T <ή> θάλασσα Prou

of pegs; {the} a thin lead weight is also glued onto the back of the board, so that it may acquire heaviness.

(4) Thus, if we drive the board upward through the notch by hand, it will fall full pelt straight through the box, as it lies around the strings. So, the strings are dyed black, in order not to be conspicuous. The underside of the board is gilded and polished to the utmost over its lower part. On the upper surface, something resembling fire is traced out, in such a way as to create the image of lightning.

(5) Once released, this falls in the middle of the figurine, since the strings are pulled taut. This [the board] remains held up above by a pin, just like the pieces of cloth, so that, when it is convenient, the cord may draw the pin and hurl the lightning bolt. As soon as the bolt of lightning falls, the figurine disappears as follows: there is another piece of cloth made just like the other coverings, but small, in order that the cloth covers exactly the figurine. On this, sea is painted like that which surrounds the figurine and the waves.

(6) καὶ εἴ τι ἄλλο φαινόμενόν ἐστι τῶν ἑγγίων, προσαπονενέμηται, ὅπως ἐπικαλυφθέντος τοῦ ζῳδίου τὸ <ὀθόνιον ἦ> ὅμοιον. καὶ ἐκ τῶν ὀπισθεν δεῖ τὸ ὀθόνιον ὁμοίως θαλασσοειδεῖ χρώματι προσαποκεχρῶσθαι. ἵνα δὲ {ἐπικαλυπτόμενον} μηδαμῶς φανῇ τὸ ὀθόνιον, ἔστιν ἄνω συνεστραμμένον καὶ κρατεῖται ὑπὸ τῆς μιᾶς περόνης, ὑφ' ἧς καὶ ὁ κεραυνὸς κρατεῖται, ὥστε ἐλκυσθείσης αὐτῆς ἅμα τε τὸν κεραυνὸν ἐνεχθῆναι ἐπὶ τὸ ζῳδίου καὶ καλυφθῆναι αὐτὸ ὑπὸ τοῦ ὀθονίου, ὥστε δοκεῖν πληγὴν αὐτὸ ὑπὸ τοῦ κεραυνοῦ ἠφανίσθαι.

5

10

(7) τὰ μὲν οὖν κατὰ τὸν πίνακα οὕτως οἰκονομεῖται. ὁμοίως δὲ καὶ αἱ ἐν τοῖς ζῳδίοις καὶ αἱ τῆς πορείας κινήσεις διὰ τοιούτων ὀργάνων πᾶσαι γίνονται, οἳ τε πίνακες πάντες ὁμοίως διὰ τούτων οἰκονομοῦνται, πλὴν ὅτι διαλλάσσονται <***>

15

1 ἑγγίων Schmidt dub. in app. crit. : ἀγγείων a : ἐγγείων Egger, rec. Prou et Schmidt 1-2 προσαπονενέμηται A^{cp} G^{cp} : προαπονενέμηται MT : <καὶ τοῦτο> προσαπονενέμηται Schmidt dub. in app. crit. 2 ὅπως a : οὕτως Prou, postea leviter interpungens ἀποκαλυφθέντος T^{ac} <ὀθόνιον ἦ> supplevi : <ὄραμα ἦ> Schmidt dub. in app. crit. 3 ὅμοιον Schmidt ante καὶ non interpunx. Prou : leviter interpunx. ed. princ. ἐκ τῶν ὀπισθεν <μερῶν> Schmidt dub. in app. crit. δεῖ Prou : δὲ a 3-4 θαλασσοειδεῖ Mc Tb^{pcsl} : θαλασσοειδῇ AG T Tb^{ac} : θαλασσοειδῇ M 4-5 ἐπικαλυπτόμενον delevi 5-6 συνεστραμμένον A^{cp} G M^{cp} : συνιστάμενον Ac Ld : ἀνεστραμμένον Prou 12 αἱ¹ om. M 14 post ὅτι lacunam statuit Schmidt secutus Prou, qui <μύθοις> suppl. : <τοῖς μύθοις> Schmidt dub. in app. crit. 14-15 post διαλλάσσονται plerique codices λείπει in margine habent : ~~λείπει~~ Ab^{m9}, sed in textu manus altera κατὰ τοὺς ἀνομοίους καὶ πολλοὺς τῶν διαγεγραμμένων τρόπους add. : ΤΕΛΟΣ Pb Vd 15 lacunam statui

(6) If anything else, of the things nearby, is seen, it is added, so that, when the figurine has been masked, <the cloth may be> all alike. The cloth must likewise be additionally painted the colour of the sea on the underside. In order for the cloth not to be seen at all {when covered}, it is rolled up aloft and propped up by the one pin which also supports the bolt of lightning, so that, when it is dragged out, the lightning bolt falls on the figurine and this is covered by the cloth at one and the same time, with the result that it [the figurine] seems to vanish being struck by lightning.

(7) Therefore, the effects in the box are managed in this way. The movements of the figurines and those of the journey all occur in a similar way through such instruments, and all the boxes are likewise managed by these means, except that they differ <***>

COMMENTARY ON BOOK ONE

I [2.3-6.8] Preface

In a succinct preface, Hero presents the subject matter of the treatise. The incipit is conventional in both form and content (see Alexander 1993: 71, 75-7), but the presence of a lacuna hinders comparison with similar openings. Stationary automata (I.3-6) are given more space than their mobile counterparts (I.2), possibly because of the author's stated preference for the former type (I.7 ἔστι δὲ... ὑπαγόντων). The words with which the opening sentence now closes are repeated at the end of I.7 and create an inclusio. As a result, the last paragraph (I.8) presents itself as an independent unit, in which Hero can affirm his editorial authority (Mansfeld 1998: 52).

I.1 [2.3-4] Τῆς αὐτοματοποιητικῆς... ἡξιωμένης. For a similar opening, cf. *Spir.* 2.4-5 Τῆς πνευματικῆς πραγματείας σπουδῆς ἡξιωμένης πρὸς τῶν παλαιῶν φιλοσόφων τε καὶ μηχανικῶν, etc. (with Mansfeld 1998: 51; correct πρότερον to πρότερον? see below). As first noted by Baldi 42^r n. 1, there is no main clause following this genitive absolute. Previous translators have obviated the problem by rendering the genitive absolute as an independent sentence. Schmidt rightly suspected a lacuna after θεωρίας (I.1 [2.5]; cf. *Catoptr.* 318.11). Comparison with other scientific prefaces, most notably Hero, *Dioptr.* 188.3-9 and *Spir.* 2.4-10 (see Alexander 1993: 70 with n. 6), indicates that here, too, the author's intention to write would have been expressed in the first main clause of the preface, and that such a clause would have followed the opening subordinate clause. However, nothing suggests that the main clause here should coincide with *Spir.* 2.7-10 ἀναγκαῖον ὑπάρχειν νομίζομεν καὶ αὐτοὶ τὰ παραδοθέντα ὑπὸ τῶν ἀρχαίων εἰς τάξιν ἀγαγεῖν, καὶ ἃ ἡμεῖς δὲ προσευρήκαμεν εἰσθέσθαι, as tentatively proposed by Schmidt in his app. crit. This is not because, as has been asserted by Olivieri (1901: 434), Hero draws on Philo exclusively for Book Two, but because in the *Automata*, just as in the *Dioptra* (cf. *Dioptr.* 188.5-9 ἀναγκαῖον... προάξει), he prioritises improving and ameliorating earlier models over order and inventiveness.

For the use of the term πραγματεία (and its corresponding verb πραγματεύομαι) in scientific prefaces, see Alexander (1993: 96-7), where the

present passage, Hero, *Dioptr.* 188.3 (Τῆς διοπτρικῆς πραγματείας) and *Spir.* 2.4 (quoted above) are cited among others (add XX.1 [64.3] πραγματευθῆναι). The term clearly refers to the subject of the treatise rather than to the treatise itself ('Il Trattato delle Machine Se moventi', Baldi 16^v; amplified in Couture 243). Murphy 11 ('The study of automaton-making') overemphasises its theoretical connotations. Schmidt's translation is more puzzling: 'Die Schaustellung der Automaten (Automatentheater)' (339). For the term in a more concrete sense ('device'; not recorded by LSJ s.v.), cf. XXVIII.2 [100.15].

I prefer προτέρων (**GM**) to πρότερον (**AT**), which has been adopted by Schmidt. Nowhere else in the Heronian corpus does the substantivised adverb occur with reference to predecessors. When referring to predecessors, Hero uses either prepositional phrases (οἱ πρὸ ἐμοῦ: *Dioptr.* 188.5-6; οἱ πρὸ ἡμῶν: V.1 [20.8], XX.1 [64.8], *Bel.* 73.6, *Dioptr.* 188.11, 292.22, *Metr.* 4.6) or substantivised adjectives (οἱ ἀρχαῖοι: II.12 [14.11], XX.5 [68.1], XXII.1 [70.4], *Deff.* 104, *Metr.* 72.29, *Spir.* 2.9, *Stereom.* 1.21.3; οἱ παλαιοί: I.7 [4.22]; cf. *Bel.* 112.9-10; οἱ πρότεροι: *Dioptr.* 292.24-5).

I.1 [2.4-5] τὸ ποικίλον τῆς ἐν αὐτῇ δημιουργίας. Tybjerg (2003: 458-9) has argued that Hero exploits the metaphorical meaning of the term ποικίλος ('artful', 'wily', LSJ s.v. III.3.c) in order to establish a connection between mechanical craftsmanship, cunning intelligence (μῆτις) and the production of wonder. To support her argument, she cites Hes. *Th.* 511 and A. *Pr.* 308, where the term refers to Prometheus' cunning. However, she ignores the fact that the notion of ποικιλία is strongly associated with μῆτις only in the Archaic and Classical periods (see Grand-Clément 2015: 407-10, citing Detienne-Vernant 1974: 25-31). Rinaudo (2009: 59 with n. 141) has pointed out that from the fourth century onwards ποικίλος usually means 'diverse' or 'various' (Grand-Clément 2015: 407 misunderstands this to mean that 'by the Hellenistic period the adjective retains only the meaning of "varied"'), and it is in this sense that Hero primarily uses the term. What is even more interesting to note is the aesthetic effect that Heronian ποικιλία produces upon the audience. Several sources attest to the pleasure arising from ποικιλία, and Ps.-Plu. *Lib. Ed.* 7b explicitly mentions its relieving effect in connection with dramatic performances (Bevegani 2014: 322-4; cf. Arist. *Po.* 1459b26-31, with Micallella 2009: 247-8). Hero's references to πολλά τε

καὶ ποικίλαι διαθέσεις (XX.2 [64.12]; cf. *Spir.* 2.18, with reference to the natural elements) and to a broad range of dissimilar movements (XXII.2 [70.16]; cf. *Spir.* 28.14-15) suggest the intentional use of kinetic *varietas* to entertain and captivate the audience. Hero's own arrangement is, after all, one full of delight (II.12 [14.14-16]; cf. XXI.2 [68.17-18]). Another aspect of ποικιλία is its ability to stimulate more than one sense (see Grand-Clément 2015: 413-15). Hero's descriptions of the devices engage the reader's imagination not only on the visual level, but also on the auditory and tactile levels (Roby 2016: 116-18). Information about sound effects (woodworking sounds: I.5 [4.13], XXII.4 [72.3], XXIV.4 [82.20]; kettledrums and cymbals: IV.2 [18.10-11]^{bis}, IV.3 [18.19-20], XIV.1 [50.16-17], XIV.2 [52.2] and [52.5-6]; peal of thunder [or similar]: XX.3 [66.4], XX.4 [66.14], [66.15] and [66.18], XXII.6 [74.1]), along with tactile and material indications (e.g. lightness: II.2 [6.18] and [8.1], II.9 [12.9], IX.4 [32.5], XXIII.1 [74.7], XXIV.1 [80.7]; smoothness: II.3 [8.4-5], XVI.1 [54.11], XXIV.2 [82.2], XXVI.2 [92.2]), contributes to recreating a multi-sensory experience for the reader, thus enhancing (syn)aesthetic appreciation of the work; on aesthetic-oriented descriptions in the treatise, see Roby (2016: 146 with n. 25), citing, among others, II.12 [14.12] and XV.2 [52.12-14] (add XXVI.1 [90.12-13] τόπους κενούς... ἰδίως ἀπεργαζομένους).

I.1 [2.5] τὸ ἔκπληκτον τῆς θεωρίας <*>.** This expression is not easy to translate, mainly because θεωρία has multiple meanings. Alexander (1993: 59; cf. 97-8) interpreted the term to mean 'intellectual study pursued for its own sake' (see LSJ s.v. III.2.b), whereas other scholars, including editors and translators, understood it as 'spectacle' (Baldi 16^v; Schmidt 339; Murphy 11, adapted by Tybjerg 2003: 451) or 'sight' ('vista', Cambiano 1994: 621; cf. LSJ s.v. III.3). The latter sense is certainly the primary one, as confirmed by the reference to the notion of ἔκπληξις, strong emotional impact upon the audience (cf. esp. Anon. *Vit. Aesch.* 14 and Pl. *Ion* 535b2-3, with Pace 2008: 232-3; on the adjective ἔκπληκτος, see below). In order to uncover deeper levels of meaning, we must turn to Hero's concept of wonder.

According to Tybjerg (2003: 449, 463-4), Hero's concept of wonder is two-fold: on the one hand, it refers to 'intellectual surprise', that is to say, the kind of wonder experienced when learning about the causes of mechanical phenomena

(*Mech.* 2.33 = 172.4-11 Nix); on the other hand, it refers to Aristotle's aporetic wonder (*Metaph.* 982b12-21 and 983a11-21, where he mentions automata), which the philosopher describes as leading to knowledge. Tybjerg (2003: 464) implies that the latter form of wonder is particularly characteristic of automata (see already Meißner 1999: 58-9, cited by Roby 2016: 147), insofar as it stems from an epistemic disparity between the uninformed audience and the experienced mechanic. Hero's wonder, however, is much more than this. As shown by Nightingale (2001: 49-53; 2004: 261-5), in the *Parts of Animals* (645a7-23) Aristotle conceives of an aesthetic form of wonder that accompanies, rather than precedes, the contemplation (θεωρία) of animals. What is most relevant here is that, in order to illustrate the investigation of the animal world, Aristotle adduces the example of artistic representations (*PA* 645a11-15):

καὶ γὰρ ἂν εἴη παράλογον καὶ ἄτοπον, εἰ τὰς μὲν εἰκόνας αὐ-
τῶν [i.e. τῶν ζώων] θεωροῦντες χαίρομεν ὅτι τὴν δημιουργήσασαν τέχνην συν-
θεωροῦμεν, οἷον τὴν γραφικὴν ἢ τὴν πλαστικὴν, αὐτῶν δὲ τῶν
φύσει συνεστώτων μὴ μᾶλλον ἀγαπῶμεν τὴν θεωρίαν, δυ-
νάμενοί γε τὰς αἰτίας καθορᾶν.

It would be strange, and contrary to reason, if we take pleasure in contemplating representations of these things [i.e. the animals] – because we are gazing at the art which fashioned them, as, for instance, painting or sculpture – but do not take more delight in the contemplation of those things formed by Nature, despite being able to observe the causes.

Commenting on this passage, Nightingale (2001: 50; 2004: 263) notes that both artistic and philosophic contemplation entail the theoretical apprehension ('"viewing"') of a technical design. This aspect is brought out most clearly by the phrase τὴν δημιουργήσασαν τέχνην συνθεωροῦμεν (the verb συνθεωρέω here 'indicates the desirability... of an aesthetic experience of mimetic art', Halliwell 2002: 181). In order to properly understand Hero's notion of wonder, we must therefore take into account the fact that automata are, by definition, mimetic objects (*Gem. ap. Procl. in Euc.* 41.13-14; cf. Papp. 1024.26-7; Cambiano 1994: 624-5; Introduction, pp. lxvii-lxviii with n. 107). Another Aristotelian

passage helps us gain a clearer insight into the ways in which aesthetic wonder would have arisen from the θεωρία of automata. In the *Poetics* (1448b15-19), the Stagyrte distinguishes between the pleasure derived from recognising and understanding a mimetic work qua representation and the pleasure taken in technical craftsmanship (ἀπεργασία), colour and other material properties. As Halliwell (2002: 185) cautions, however, such distinction is possible only as a result of an imperfect aesthetic experience. The passage cited above from the *Parts of Animals*, by making repeated reference to theoretical activity, indirectly confirms this. Thus, just as mimetic works are the product of a δημιουργήσασα τέχνη (PA 645a11), Hero's automata are δημιουργήματα (I.2 [2.14]), and it is telling that at I.7 [4.22-6.2] the reason adduced to explain why the crafters of automata (οἱ δημιουργοῦντες) would traditionally have been called 'wonder-workers' is, indeed, τὸ ἔκπληκτον τῆς θεωρίας (Cambiano 1994: 621). In this way, Hero creates a link between everlasting, if not ever-growing, wonder (cf. Aristotle's definition of ἔκπληξις as θαυμασιότης... ὑπερβάλλουσα, *Top.* 126b17) and the aesthetico-cognitive apprehension of the automata as both mimetic artworks and crafted artefacts, an experience that allows the audience to take 'ekplectic' pleasure in the recognition and understanding of intricate mechanical devices as representational objects and, at the same time, to luxuriate in artistic and material features (e.g. technical accuracy: XXIV.1 [80.8], XXVI.1 [90.13]; colour: XXIV.2 [80.11-13], XXVIII.3 [102.1-2], XXX.4 [108.5], XXX.6 [110.3-4]). Wonder in the *Automata* can, but does not necessarily have to, arise from ignoring the mechanical causes behind the spectacles. Ripe with meaning, the expression τὸ ἔκπληκτον τῆς θεωρίας would have alerted the reader to the aesthetic sense of wonder felt, in varying degrees, when 'viewing', 'contemplating' and 'studying' the automata. All in all, Hero's wonder does not merely concern, as Berryman (2009: 51-3) maintains, the spectators' perceptions of mechanics, but first and foremost its 'theory' in both its visual and philosophical sense.

For ἔκπληκτος in the active sense of 'astounding', LSJ s.v. IV cite only *RFIC* 53 (1925) 208 = *SEG* 3.774.5 = *IC* 3.4.38.5 = *Ep.* 44.5 Martínez Fernández γλάθιας ἐκπλήκτους (first century BCE c.). Unsurprisingly, Crönert (app. crit. to *SEG* 3.774.5) glosses it as follows: ὥστε ἐκπλήττεσθαι πάντας ὁρῶντας. According to Levi (1925: 209), who first published the Cretan inscription, the ad-

jective bears this sense also at Orph. *H.* 39.10 (erroneously cited as 38.10) ψυχῆς ἐκπλήκτου. But the meaning will most certainly be passive there; see LSJ s.v. II; Fayant (2014: 334), translating ‘épouvantée’.

On the lacuna, see note on I.1 [2.3-4].

I.1 [2.6-7] ἔστι γάρ... παραλαμβανόμενον. This powerful rhetorical statement presents automata-making as an encapsulation of mechanics (Roby 2016: 266-7; ‘sintesi e coronamento di tutta la meccanica’, Ferrari 1985: 266). Roby (2016: 266) finds it remarkable that mechanics is explicitly described as consisting of ‘parts’. But cf. Ph. *Bel.* 78.26 (ἄλλο μέρος τῆς μηχανικῆς, in reference to pneumatics) and Hero, *Bel.* 72.5-6 (artillery-construction).

Note the use of the phrase ὥς συνελόντι εἰπεῖν, which adds rhetorical force to the statement (*pace* Alexander 1993: 94, who, however, omits the present passage from his list of expressions for ‘briefly’ in scientific writings). Cf. I.6 [4.17] (ἀπλῶς).

I.1 [2.7-8] διὰ τῶν... ἐπιτελουμένων. The verb ἐπιτελέω (‘complete’, ‘finish’) occurs four other times in the treatise, three times with reference to mechanical movements (XVIII.3 [60.5], XIX.4 [62.10], XIX.5 [62.16]; cf. LSJ s.v. I.1), once with an indeterminate and neuter subject (XII.3 [44.2]). The latter occurrence (τὰ ἐξῆς ἐπιτελεσθήσεται) clearly refers to the sequence of mechanical movements described at XII.4 [44.8-11]. Here, therefore, Hero appears to use the verb to refer not to mechanical knowledge as such (Roby 2016: 266-7, who takes the participle to refer to the ‘parts’ of mechanics; so also Murphy 11), but rather to the various processes involved in the construction of automata, processes which, as a whole, reflect the application of a number of different mechanical principles (cf. ‘was... ausgeführt wird, zur Anwendung’, Schmidt 339). This understanding of the verb also agrees with the immediately following context (I.2-6 [2.9-4.19]), where stress is repeatedly laid on the automatic movements that take place in both the mobile and the stationary automaton.

For κατὰ μέρος, cf. IV.4 [20.7] (components of the mobile automaton), XX.5 [66.20] and XXII.3 [70.19] (both referring to the scenes of the Nauplius play), XXX.1 [106.7] (description of the disappearance of Ajax).

I.2 [2.9] ἡ ἐπαγγελία. The term ἐπαγγελία occurs only twice in Hero, here and at *Dioptr.* 286.20-1 (διοπτρικὰς ἐπαγγελίας), where it seems to be used synonymously with πρόβλημα ('dioptrischen Problemen', Schöne 1903: 287; so also Lewis 2001a: 281). Here the term refers to that which automata-making 'promises' (so Baldi 16^v and Schmidt 339; cf. 'quod hinc expectatur', Couture 243; LSJ s.v. 3) to accomplish, and hence to the 'subject' (or, perhaps better, 'scope', as I have translated) of automata-making (Murphy 11 freely translates 'topics to be discussed'). The relationship between these two meanings is close. Note especially Gal. *Libr. Propr.* 91.9-10 and 92.11 Müller, where the term is used synonymously with ἐπάγγελμα ('subject' of a treatise, LSJ s.v. ἐπαγγελία 6). LSJ s.v. ἐπάγγελμα 2 understand the meaning of the term as 'that which it [i.e. the treatise] purports [sic] to contain'. The connection is further strengthened by the use of ὑπόθεσις at XXI.2 [68.17] (cf. LSJ s.v. II.3; Verhasselt 2015: 614-15, on S.E. *M.* 3.3 = Dicaearch. fr. 78 Wehrli). In a similar sense, I.3 [2.17] (ὑπόσχεσις) and XXI.1 [68.7] (πρόβλημα).

I.2 [2.9-10] κατασκευάζονται ναοὶ ἢ βωμοὶ σύμμετροι. There is no need to emend ἢ to καί, as tentatively suggested by Schmidt in his app. crit. The context makes it clear that Hero is referring to the types of mobile automata that can be built rather than, as Schmidt's proposal implies, to Dionysus' shrine and its associated altars (see already Baldi 42^r n. 2). Hero does not go into detail about the arrangement of his mobile automaton until ch. III, and the opening sections of the treatise are not devoid of general considerations. For more specific references (introduced by οἷον), cf. I.5 [4.12-13] and I.6 [4.16-17] (both referring to the figures in the stationary automaton).

By the adjective σύμμετρος, Hero here intends to denote proper proportion between the parts of automata ('proportionati', Baldi 16^v; 'of appropriate size', Murphy 11; cf. 'apte', Couture 243) rather than moderate size ('von mässigem Umfange', Schmidt 339). The adjective recurs in the same sense at IX.5 [32.7-8] (of the hole through which the millet flows) and XXV.2 [86.6] (of the thickness of a rod). The emphasis Hero lays on proportionality and suitability recalls Philo's descriptions of artillery engines, the components of which are repeatedly qualified as 'proportionate' (Schiefsky 2015: 625-6 with n. 23, citing Ph. *Bel.* 53.24-5, 54.15 and 54.21 [συμμέτρως]; cf. also 63.28, 66.7 and 67.12-13). Vit-

ruvius, too, uses the concept of ‘symmetry’ to refer to proportionality in machines: Vit. 10.10.1 (ballistae and catapults). On Vitruvius’ concept of *symmetria*, see Lefas (2000).

For σύμμετρος as indicating a moderate size, cf. XXV.4 [86.20] (of a gap, as at *Dioptr.* 242.1).

I.2 [2.10-11] αὐτόματοί... τόπους. On Hero’s notion of αὐτόματος, see Berryman (2002: 245), who, drawing upon Galen’s comparison between living organisms and theatrical devices (*Foet. Form.* 4.688-9 Kühn), stresses that it is the internal constitution of the devices that allows a sequence of causally dependent movements to take place ‘automatically’ (namely, without constant human intervention); see also Berryman (2003: 365; 2007: 39; 2009: 142 and, more generally, 201-5). This conception emerges most strikingly in XXVI.6 [94.14-17], where Hero emphasises the centrality of mechanical design to the automatic rolling and unrolling of a scroll of papyrus (**Fig. 30**): ἵνα οὖν αὐτόματος παραγένηται ὁ χάρτης... δεῖ προμηχανήσασθαι ταῦτα, with which cf. Ph. *Bel.* 74.16-18 ἦν δὲ μεμηχανημένον, ὥστε αὐτομάτην [sc. τὴν χεῖρα]... ἀποσχάζεσθαι. At the heart of any automatic sequence of movements, then, is not external agency (cf. IX.5 [32.9-12]), but a ‘stored power source’ (Berryman 2009: 202-3) that Hero calls ἐνέργεια (I.7 [4.20]; cf. *TGL* s.v. αὐτόματος: ‘[α]ὐτόματοι autem μηχαναὶ dicuntur αἱ καθ’ αὐτὰς ἐνεργοῦσαι’). For the use of the term in its original sense of ‘spontaneous’, ‘acting of one’s own will’ (Belardi 2005: 44-7 with n. 21), cf. XV.3 [52.17] and [52.20] (both negated).

I follow Brinkmann in emending προσάγονται to προάγοντες in preference to Diels’ emendation προσαγόμενοι, printed by Schmidt. The middle voice of the verb προσάγω never means ‘move forward’ (‘heranbewegen’, Schmidt 339; so also Murphy 11), but ‘bring to (oneself)’, ‘bring over to one’s side’, ‘take to oneself’, ‘take up’ (LSJ s.v. B.I-II; used only once at *Dioptr.* 190.16 προσα<γα>γόμενοι [sc. μηχανήματα] τοῖς τεύχεσιν). By contrast, the verb προάγω – which Hero uses elsewhere in the figurative sense of ‘advance’ (*Metr.* 2.7) – can be used intransitively to mean ‘lead the way’, ‘make an advance’ (LSJ s.v. II.1; cf. Evans 1954: 9). LSJ s.v. II.1 compare the Platonic instances of the verb (Pl. *Phdr.* 227c1 and *Phd.* 90b5) with X. *An.* 6.5.6, where it refers to the march of Cyrus’ army, and Bailly s.v. adds Plb. 14.10.1 (προῆγον ἐπὶ θάλατταν).

The corruption of *προάγοντες* to *προσάγονται* probably arose under the influence of *κατασκευάζονται* in the preceding line. For the scribal confusion between *προάγω* and *προσάγω*, see LSJ s.v. *προάγω* I.2.c (Ruf. fr. 68 Daremberg-Ruelle = Aët. 5.84) and II.3 (Hdt. 9.92).

With *κατά τινας ὁρισμένους... τόπους*, cf. IV.1 [18.3-4] (*ἐπὶ τινὰ ὁρισμένον τόπον*).

I.2 [2.11-12] *τῶν ἐνόντων... κινεῖται*. The reference is to mechanical human figures of the kind one finds in Hero's automata. The participle *τῶν ἐνόντων* no doubt means 'being in(side)' (so Schmidt 339 and Murphy 11) rather than 'being on (top of)' ('che sopra vi sono', Baldi 16^v); see LSJ s.v. *ἐνεμι* I.1.a. Couture 243 translates more vaguely 'ibi dispositarum'.

As noted by Baldi 42^{r-v} n. 3, Hero generally uses the term *ζῳῖδιον* to refer to human-shaped figures. Nowhere in the text does the word refer to animal figures (*pace* Rossi-Pagano-Russo 2010: 155, who translate 'figurines representing animals'; cf. rather *Spir.* 136.23, 138.3, 144.10, 328.2). Hero's use conforms to the primary usage of the word (on which, see Kosmetatou 2004: 481: 'the term *ζῳῖδιον*... refers primarily, though *probably* not exclusively, to statuettes of human figures' [my emphasis]).

The adverb *ἰδίᾳ* appears to be used synonymously with *αὐτόματος/αὐτομάτως*. For the same sense, cf. *Dioptr.* 194.15-16 (*ἰδίᾳ στραφήσεται τὸ τυμπάνιον*). Elsewhere Hero uses it in the sense of 'separately' (*Geom.* 322.23, *Spir.* 112.14 and 270.27). Previous translations have placed emphasis on the distinctiveness of each figure's motion. Couture 243 has 'proprio et sibi singulari motu', whereas Murphy 11 believes that the figures move 'independently' of one another. More neutrally, Baldi 16^v ('con un proprio moto') and Schmidt 339 ('für sich'). Note, however, that the figures of Dionysus and Nike are described as moving together (IV.2 [18.13-14], XIII.7 [48.13-14], XIII.8 [50.2-3] and [50.5-6]).

I.2 [2.12-13] *πρὸς λόγον... ἀρμόζοντα*. Note chiasmus. For *πρὸς λόγον*, cf. XXI.1 [68.10] (with genitive).

Baldi 16^v ('propositione... che s'ha inanzi') translated the words *προκειμένην πρόθεσιν* correctly, but he misconstrued the syntax, taking

ἁρμόζοντα as referring to λόγον. This led him to misunderstand the term πρόθεσις – additionally translated as ‘proposito’ (‘purpose’, cf. LSJ s.v. II.1) – as denoting the ‘story’ (Baldi 42^v n. 4), and to take προκειμένην as referring both to πρόθεσιν and to μῦθον. But ἢ is clearly disjunctive. At any rate, Baldi’s translation is more accurate than Schmidt’s ‘dem vorliegenden Plane’ (339). Murphy 11 mistranslates, omitting the participles: ‘according to the argument of the *arrangement* or story’ (my emphasis). Couture 243 omits even more: ‘qualem [i.e. motum] exigit fabula’. For πρόθεσις as denoting advance planning, cf. *GEL* 30.63. (The idea is here brought out by the use of the verb πρόκειμαι, as at I.4 [4.8].)

The term μῦθος is used elsewhere in the treatise to refer to the stories enacted in stationary automata (generic references: I.3 [2.19], I.4 [4.8] and [4.9], I.5 [4.12], XXII.1 [70.9], XXII.2 [70.11] and [70.15] [both plural]; Nauplius play: XX.2 [64.11], XXII.3 [70.18], XXII.6 [74.3]). The use of the word here suggests that mobile automata, too, would somehow have allowed the (re-)enactment of polyscenic mythical narratives. For the distinction between monoscenic and polyscenic narrative regarding Hero’s automata, see Prou 138 and Cambiano (1994: 614), both of whom speak of ‘acts’ (but see the caveat in Marshall 2003: 261-2 n. 3).

I.2 [2.13-14] εἰς τὸν...τόπον. Cf. *Spir.* 278.15-280.1 εἰς τὸν ἐξ ἀρχῆς τόπον ἀποκατασταθήσεται [sc. τὸ ὕδωρ]. For this sense of ἀποκαθίσταμαι (‘return’), see also XIII.8 [50.5] (rotating Nike and Dionysus), *Spir.* 8.6-7 and 8.10; other comparable passages cited by LSJ s.v. ἀποκαθίστημι II.1 (add Ph. *Bel.* 71.14 ἐπὶ τὸν ἐξ ἀρχῆς ῥυθμὸν ἀποκαθίσταται). The use of the verb in XIII.8 [50.5] parallels its use in geometry, where the verb describes figures, both plane and solid, completing a full rotation: *DGE* s.v. I.3 (Archimedes; but the usage is already attested in Euclid: Heath 1897: clxix); compare especially Hero, *Deff.* 7, 27^{bis}, 76, 83, 95 and 97, *Metr.* 126.15. For ἀποκαθίστημι in the (unusual) sense of ‘lay’, cf. XXIII.4 [76.9].

On the lacuna suspected by Schmidt after τόπον, see note on III.2 [16.8-10].

I.2 [2.14-15] δημιουργήματα. Qua *nomen rei actae* in -μα, the word denotes the automata as the result of the crafting process (δημιουργεῖν: I.7 [4.22-6.1], IV.4

[20.3-4]). According to Chantraine, *DELG* s.v. δημιουργός, the term δημιουργήμα, meaning ‘work of art’, is attested late; but see, for instance, Aesop. 102, D.H. *Comp.* 1 and 10, [Longin.] *Subl.* 13.4. As noted by LSJ s.v., the word is used in a biological context (Hierocl. *El. Eth.* col. I 11) to designate a living ‘creature’. On the possible Chrysippean origin of this meaning, see Bastianini-Long (1992: 375), who recall the contrast drawn by Porph. *Gaur.* 47.12-13 between the ἔργα of nature and the δημιουργήματα of a shipbuilder. With this passage one should compare Plu. *Ser. Num.* 559d = Posidon. fr. 367.27-8 Theiler τὸ γεννηθὲν οὐχ ὥς τι δημιουργήμα πεποιημένον ἀπήλλακται τοῦ γεννήσαντος· ἐξ αὐτοῦ γὰρ οὐχ ὑπ’ αὐτοῦ γέγονεν.

I.3 [2.17] **ὑπόσχεσις**. Note the *variatio* with ἐπαγγελία (I.2 [2.9], on which see note ad loc.).

I.3 [2.17-18] **ἐπὶ τινος... ἔχων**. At first sight, it seems strange that a three-dimensional object such as the stationary automaton is designated by the word πίναξ (‘board’, ‘plate’ or ‘tablet’; on the meanings of the term, see Pritchett 1956: 250). The word has received various translations. Paradigmatically, Schmidt renders it as either ‘Tafel’ (cf. ‘tavola’, Baldi; ‘tabula’, Couture), ‘Bühne’, ‘Spielhaus’ or ‘Automatentheater’; cf. ‘(toy) stage’ or ‘(toy) theatre’ (Murphy; evidently based on LSJ s.v. 8); ‘scène’ or ‘théâtre’ (Prou). More recently, Marshall (2003: 261, 263) has rightly argued that the πίναξ is a ‘box’ (cf. XXIII.1 [74.5-7] and note on II.7 [10.18-19]), while also drawing attention to the use of the term in the context of Hellenistic theatre. With its painted backdrops (cf. esp. XXIV.1 [80.4-5], XXV.2 [84.15-86.2], XXV.6 [88.12-13], XXVI.6 [94.9-14], XXVIII.1 [100.7-8], XXIX.1 [104.16-18], XXX.5 [108.15-18]), Hero’s stationary automaton recalls the changeable scene panels placed in the so-called *thyromata* (‘openings’) of Hellenistic and Roman theatres: for details on the location of the πίνακες, see Penny Small (2013: 116), with further references. More specifically, it calls to mind some descriptions of painted panels in the Delian temple inventories (after 166 BCE). Among the types of Delian panels originally studied by Vallois (1913) and lately reviewed in a more systematic fashion by Jones (2014) appears the shuttered panel, which could rest on a base: [πίνακα ἐπὶ β]άσεως τεθυρωμένον (*ID* 1417 A col. I 11; further references in Jones 2014:

304*** s.vv. τεθυρωμένος [add 1414 b col. I 21-23] and ἐπὶ βάσεως). It thus becomes evident that what Hero means by κιονίσκος is, indeed, a pedestal supporting the automaton (for this suggestion, see Baldi 42^v n. 5, who translates ‘pedistalletto’; cf. also XXI.1 [68.8]). The connection between the nomenclature chosen for the stationary automaton and the Hellenistic tradition of panel painting is strengthened by Hero’s description of the primitive type of device (XXII.1-2 [70.4-14]), a πίναξ equipped with shutters and with a face painted on it (πρόσωπον γεγραμμένον). This description not only harks back to the καλύνματα προσώπων (IG 4².1.102 A col. I 57 and 68; cf. A col. I 58-9 and 102 B col. I 77) that were set into ceiling coffers in the Sanctuary of Asclepius at Epidaurus in the early fourth century BCE (on these, see Hellmann 1992: 92 with n. 23), but also evokes the portraits (πίνακες εἰκονικοί) so frequently mentioned in the Delian inscriptions; cf. esp. ID 1403 Bb col. I 57 πίνακα πρόσωπα ἔχοντα τρία (erroneously cited by Jones 2014: 304** s.v. πρόσωπα ἔχοντα τρία as 1403 B.1.28).

For the derivative πινάκιον, cf. XX.5 [68.3].

I.3 [2.19] <φαίνεται> διάθεσις ζφδίων. I agree with Schmidt that a lacuna should be supplemented with <φαίνεται> (he prints a lacuna in the Greek text, but nonetheless translates his proposed supplement: ‘sieht man’, 341). Brinkmann’s proposed <γέγραπται> might seem equally attractive, especially since the following reference to the arrangement of figures (I.4 [4.2]) is to ἡ...τάξις γεγραμμένη (note the presence of the article). As the passage goes on, however, the emphasis is on the spectator’s viewpoint, as indicated by the reiteration of the perceptual verb φαίνομαι and its compounds. (Tybjerg 2003: 457 n. 46 erroneously refers to eleven occurrences of φαίνω [*sic*] within the portion I.3-5 [2.17-4.20] as against nine, including ἐπιφαίνεσθαι and ἀφανίζεσθαι, within the same portion: cf. Cambiano (2011: 31). A further argument against Brinkmann’s proposal is that the passive of γράφω is never used of διάθεσις in Hero. The omission of φαίνεται is easily explained palaeographically (the form occurs twice in close proximity: I.4 [4.2] and [4.4]).

The term διάθεσις, corresponding to the Lat. *dispositio*, appears to be used in three different ways in the treatise. In a technical sense, as an inheritance from professional criticism (cf. Vitr. 1.2.1-2 and, most relevantly, Plin. *Nat.* 35.80,

with Pollitt 1974: 23, 163-4), it refers to the position of the figures (or parts thereof) in relation to one another (here, as at I.4 [4.4] and [4.6], XXII.2 [70.10], XXIV.1 [80.5]; cf. I.4 [4.9]). This sense is closely related to the basic meaning of the word ('arrangement', LSJ s.v. 1, citing Aristotle's definition of *διάθεσις* as τοῦ ἔχοντος μέρη τάξις, *Metaph.* 1022b1; cf. I.4 [4.2], quoted above). In a broader sense, as an extension of the previous meaning, it signifies the scenic 'arrangement' (cf. 'subject', 'content' of a painting: Pollitt 1974: 162-3, with references) and/or the theatrical '(re)presentation' (LSJ s.v. I.2.a, citing XX.2 [64.11]; cf. also I.7 [4.22], I.8 [6.5] and [6.7], II.12 [14.11], [14.14] and [14.15], IV.4 [20.6], XX.4 [66.9], XX.5 [66.19], XXI.1 [68.10], XXI.2 [68.18] and [68.19], XXII.1 [70.4], XXII.4 [72.5], XXII.6 [74.4]). This meaning overlaps, at least to some extent, with the rhetorical use of the term ('delivery' of a speech, LSJ s.v. I.2.a; cf. Tybjerg 2003: 455 with n. 41, who, however, also cites in this connection XXIV.1 [80.5]); in this sense, therefore, *διάθεσις* can be understood to denote the spectacle (*ἐπίδειξις*) as *delivered* to the watching audience ('disposizione scenica esibita davanti a un pubblico', Cambiano 1994: 613; on *ἐπίδειξις*, see note on IV.4 [20.1]). In a narrower sense, it refers to configurations of a mechanical nature (I.8 [6.4] and XX.2 [64.12]). This meaning is brought out most clearly in XX.2 [64.12-14]: *πολλαί τε καὶ ποικίλαι διαθέσεις... οὐ φαύλως οἰκονομούμεναι πλὴν τῆς μηχανῆς τῆς περὶ τὴν Ἀθηνᾶν* (Schmidt 405 mistranslates here: 'Aufführungen'; cf. 'scenes', Murphy 28). For *διάθεσις* as mechanical 'arrangement', 'design', cf. Ph. *Bel.* 56.14, 59.28, 68.16-17, 68.20, 72.22-3, 76.21, 77.11-12, 78.23; Hero, *Bel.* 73.7 and 112.10.

I.3 [2.19-20] *πρός... διεσκευασμένων*. Cf. XXII.2 [70.9] *ἔς τινα μῦθον διεσκευασμένα*.

I.4 [4.1-2] *κεκλεισμένου... ἀνοίγονται*. H. Schöne proposed adding <ἐξ ἀρχῆς> after οὖν. This supplement is unnecessary because the context makes it clear that Hero is referring to the first opening of the doors. The *πίναξ* is presumed to be initially closed also at XXI.1 [68.7-9] and XXII.3 [70.19-20] (*ἀνοιχθέντος ἐν ἀρχῇ τοῦ πίνακος*).

I.4 [4.3-4] καὶ μετ' οὐ... αὐτομάτως. The doors of the πίναξ have not previously been described as closing automatically. I have therefore transposed the words πάλιν αὐτομάτως, making them follow ἀνοιχθεισῶν (cf. αἱ θύραι αὐτόματοι ἀνοίγονται, I.4 [4.1-2]) instead of τῶν θυρῶν ('die Thüren wieder von selbst geschlossen und geöffnet', Schmidt 241; Murphy 11 has it the other way around, while Baldi 16^v unmistakably takes πάλιν to refer to ἀνοιχθεισῶν). The πίναξ is initially described as having open doors (θύρας ἔχων ἀνοιγομένας, I.3 [2.18]), which, however, is easily explained by the general and introductory character of the passage. The initial position of the πίναξ no doubt presupposes closed doors (κεκλεισμένου οὖν τοῦ πίνακος, I.4 [4.1]; see previous note). For this closing and opening of the doors, cf. XXI.1 [68.10-12] (where πάλιν is perhaps better taken as referring to φαίνεσθαι).

I.4 [4.5] ἀρμόζουσα τῇ πρότερον φανείσῃ. Cf. I.4 [4.7] ἀρμόζουσα τῇ πρότερον κειμένη (with *variatio*). For this use of ἀρμόζω, meaning 'correspond', see LSJ s.v. II.1.b (add III.1 [16.1], of capitals).

I.4 [4.5-7] καὶ πάλιν... κειμένη. A careless repetition of the immediately preceding lines (I.4 [4.3-5]), according to Baldi 42^v n. 7. This could possibly explain why Couture 244 omits translating these words, which, however, do not seem redundant. Each appearance of the figures as described at I.4 [4.2-9] (cf. XXI.1 [68.9-14]) corresponds to a separate scene in the stationary automaton. From XXII.1-2 [70.4-12], it is obvious that the earlier prototype of πίναξ displayed no less than three scenes, which were later expanded into a five-scene sequence (cf. Introduction, p. lxxx n. 144). The omission of these words would therefore result in an incomplete succession of scenes, with the third and potentially final scene described as optional (I.4 [4.8-9]).

I.4 [4.7-9] καὶ ἦτοι... φαίνεται. The manuscripts read ἀπαρτίζουσα instead of ἀπαρτίζει (R. Schöne), an obvious enough emendation (also adopted by Schmidt). Schmidt's tentatively suggested addition of <αὕτη> (referring to ἑτέρα διάθεσις in the previous clause) seems necessary to make the clause more intelligible. Cf. *Spir.* 180.11-182.3 ἀνοιχθήσονται αἱ θύραι· ἦτοι γὰρ αὗται δι' ἑαυτῶν αὐτομάτως ἀνοιχθήσονται... ἢ ἔξουσί τι ἀντισηκοῦν βάρος τὸ ἀνοίγον αὐτάς.

The phrase τὸν προκείμενον μῦθον denotes the ‘story’, or perhaps even (dramatic) ‘plot’ (LSJ s.v. μῦθος II.5; so Landels 1978: 204), that has been ‘set forth’ (so Baldi 17^r and Couture 244), with adverbial prefix προ- presumably meaning both ‘forth’ and ‘beforehand’ (LSJ s.v. πρό D.III.2 and 5): cf. ‘the planned story’ (Murphy 11). A less faithful interpretation in Schmidt 341: ‘das zu Grunde liegende Stück’. On πρόκειμαι as denoting foreplanning, see note on I.2 [2.12-13].

I.5 [4.10-11] τῶν φαινομένων... ἕκαστον. There appears to be no need to adopt, as Schmidt does, R. Schöne’s conjecture ἐν (πίνακι ἐν ἕκαστον), originally meant to correct the letters which in **A** are found *in margine* and in **T** and **M** *in textu*. Schmidt failed to notice that **A** corrects πίκακι to πίνακι. The marginal letters να are therefore probably intended to repeat the correction for reasons of clarity. Instead of breaking the word at the end of the line, the scribe writes the last two letters slightly above the line and partially into the margin, which can possibly explain what we find in **M**, namely the reduplication of the ι and the subsequent intrusion of ἵνα. Cf. also I.2 [2.11-12] τῶν... ζωδίων ἕκαστον.

I.5 [4.12-14] ἃ μὲν πρίζοντα... ἀληθείας. These lines lend themselves to close comparison with XXII.4 [72.1-4] τὰ μὲν πρίζοντα... ἀληθείας. Based on the resemblance between the two passages, Schmidt hesitantly proposed adding <ἃ δὲ ἀρίσι καὶ τρυπάνοις χρώμενα> after I.5 [4.13] ἐργαζόμενα and <τὰ δὲ σκεπαρνίζοντα> after XXII.4 [72.1] πρίζοντα. Tempting though it may seem, restoration of either passage need not be urged. The two textual portions do exhibit a high degree of formal correspondence, but this does no more than point to a common source. Assuming that XXII.4 [72.1-4] are more or less directly derived from Philo, we could explain the present passage as a citation from memory or, perhaps more pertinently, as a revised quotation of the Philonic text.

Note how the lines under discussion display a carefully balanced structure and rhythmic character (but π and ρ are also repeated throughout XXII.4 [72.1-4], with ρ occurring two more times). The alliteration of π, ρ and κ, along with the homeoteleuton (πρίζοντα... σκεπαρνίζοντα, picked up by ποιοῦντα), evokes the pounding sound of the woodworkers’ tools and thereby adds to the vividness of the description. Hero’s use of such literary devices must be seen as part of a larger ekphrastic strategy of visualisation (on Imperial technical ek-

phrasis as drawing on contemporary rhetorical theories of *enargeia*, see Roby 2016: 90-1). In this connection, Roby (2016: 116-17) draws attention to how detailed descriptions of the auditory features of the machines in both the *Pneumatica* and the *Automata* stimulate the reader's imagination and enable him or her not only to 'see' but also to 'hear' the device described (see note on I.1 [2.4-5]). Hero's insistence that the figures produce noise καθ' ἑκάστην πληγὴν will surely serve a similar function. What brings Hero's description closer to rhetorical ekphrasis, however, is not just the inclusion of specific (auditory) details (note the variety of carpentry tasks mentioned in the first part of the clause), but a more general concern with verisimilitude (on the introduction of vivid details as a rhetorical strategy of verisimilitude, see Schmitz 2000: 63-8). By stating that the noise-making of the figures takes place καθάπερ ἐπὶ τῆς ἀληθείας (repeated twice more: XXII.4 [72.3-4] and XXII.5 [72.12-13], both already cited in Cambiano 2011: 31; Marshall 2003: 274, who likens the language of XXII.5 [72.10-13] to that of poetic ekphrasis), an expression which may rightly be regarded as belonging to what Halliwell (2002: 155) calls 'the traditional Greek language of "likeness(es)"' (for a list of relevant expressions, see Halliwell 2002: 20 n. 48), Hero appears to conform to the requirements of rhetorical *enargeia*: cf. esp. [Longin.] *Subl.* 15.8 and Quint. *Inst.* 6.2.30, with Webb (2009: 101-3 with n. 41, and 168). It is in this light that we can better understand both Hero's claim that the painted figures of the woodworkers must be arranged in an 'utterly plausible' pose (XXIV.1 [80.5-6] διαθέσεις... πιθανωτάτας, cf. XXI.1 [68.6-7], with a litotes, and not a positive adjective, as suggested by Tybjerg 2003: 455 n. 41) and the occurrence of the word φαντασία with reference to the sketch of the lightning (XXX.1 [108.8-9]). As variously observed in previous studies (Cambiano 1994: 625 with n. 54; Tybjerg 2003: 455-6 with n. 41; Berryman 2009: 140), Hero holds credibility and persuasiveness close to his heart, and this is where lifelikeness comes into play. Aiming for fictional plausibility, Hero combines the exercise of rhetorical effects with an explicit interest in descriptive vividness and verisimilitude. If it must have cost the reader little trouble to imagine the Greek sailors noisily repairing their ships, the watching audience would certainly not have doubted the credibility of the representation (cf. XXIV.1 [80.9], where the flushness of the arms contributes to this effect).

I.6 [4.15-17] **δύνανται δὲ... ἀφανίζεσθαι**. I take ὑπό to mean ‘under (shelter of)’ and hence ‘in(side)’ (cf. the mathematical use: LSJ s.v. C.2.b). In his app. crit. Schmidt hesitantly proposes emending to ὑπὲρ, a reading found in the margin of manuscript **La** (the letter pi is here realised neither as π nor as ϖ, but looks like *u*, in a rather compressed form; for this n-shaped pi, cf. Thompson 1912: 189, 191-4; Gardthausen 1913: 180, 196, and Pl. 4b coll. 12-13). In support of his conjecture, Schmidt cites XXII.6 [72.17] ὑπὲρ τὸν πίνακα (of fire coming out of Nauplius’ torch) and [72.20] ἄνωθεν τοῦ πίνακος, which he takes to refer to the lifting of Athena’s machine. While the torch is placed immediately above the πίναξ (XXVIII.2 [100.11-15]; but perhaps the σάνις ἐπισκοτοῦσα mentioned there can be regarded as part of the overall structure), the figure of Athena is said (XX.2 [64.15-16]) to appear ὑπὸ τὸν πίνακα (ὑπὸ **MT** : ὑπὲρ **AG**), and Hero details the mechanisms for its appearance inside the box (XXIX.1 [104.18]). Schmidt 406-7 himself prefers ὑπὸ (‘auf’) to ὑπὲρ (‘über’) at XX.2 [64.15], but warns that the prepositions are frequently confused by the scribes (*Supplementum* 112). Even assuming that the prepositions have been inadvertently swapped, ὑπὲρ does not give a satisfactory sense as no figure appears outside the πίναξ. Despite being found elsewhere (XXX.7 [110.11]), κατὰ (Diels) is palaeographically implausible.

Other interpretations of ὑπό prove infelicitous. Baldi 17^r (‘dietro la tavola’), followed by Couture 244 (‘pone tabulam’), appears to translate the phrase by analogy with ὑπὸ σκηνήν (cf. Schmidt’s suggested ‘hinter der Scene’ [341 n. 1]), whereas Murphy 11 renders it as ‘below the stage’ (cf. ‘under the platform’, Rossi-Pagano-Russo 2010: 156). I cannot find any reference either to the lighting of a fire or to the appearance of figures behind/below the πίναξ. (Note, however, that the dolphins are made to disappear into a chamber underneath the πίναξ (**Fig. 31**): XXVII.3 [98.16-18].)

I.6 [4.17] **ἀπλῶς**. On the adverb as conveying the idea of brevity, see LSJ s.v. II.3. See also *Dioptr.* 234.14. For *brevitas* as a stylistic device, see note on I.1 [2.6-7].

I.6 [4.17-18] **ὥς ἂν τις ἔληται**. I follow Schmidt in retaining the manuscript reading ἔληται. H. Schöne proposed emending to προήλεται. However, Hero never

uses the aorist of προαιρέομαι, preferring instead the present. For similar expressions, cf. Ph. *Bel.* 62.7 and 66.21-2.

I.6 [4.18] μηδενὸς προσιόντος. A phrase reminiscent of Ath. 198f (on Nysa's statue), cited in Introduction, p. lxxxviii.

I.7 [4.20-2] ἔστι δὲ... ὑπαγόντων. Hero's preference for stationary automata is reiterated in a similar fashion at XXI.1 [68.5-7] (but καὶ²... ἔχουσα is probably best understood outside the boundaries of comparison). To substantiate his preference, Hero cites two reasons: (1) the safety of the mechanism; (2) a higher degree of scenic flexibility. The first reason is clear. Because stationary automata do not involve locomotion, their operation, as well as their construction (ποίησις, XXI.1 [68.5]), is safer compared with that of mobile automata (Cambiano 1994: 615; for some of the problems associated with mobile automata, see synopsis on II). The second reason is less clear, particularly because at I.8 [6.4-7] Hero praises the scenic adaptability of the Dionysiac arrangement. Cambiano (1994: 615) takes the words μᾶλλον... διάθεσιν to mean the 'possibilità spettacolari' of the πίναξ, which he explains by virtue of the dramatic nature of the performance. However, there is no hint anywhere in the text that suggests that the two types of automaton are compared in terms of spectacular outputs and/or variety of movements. Hero's aim, as Cambiano (1994: 619-20) himself recognises, is to transmit procedural knowledge (II.12 [14.12-14], XXI.2 [70.1-3]), one that can be applied to the construction of other devices and arrangements. The higher degree of scenic flexibility of stationary automata is therefore best explained by the relative ease with which the automata-maker (re-)arranges and prepares the πίναξ for performance ('facilité qu'il [i.e. le théâtre fixe] offre aux combinaisons scéniques', Prou 139).

On ἐνέργεια as 'mechanism', 'action', see LSJ s.v. I.1.a, who cite only the present passage. The term occurs also at I.8 [6.7], where it appears to refer to the actualisation of the arrangement. The latter usage recalls the philosophical use of the term. Cf. especially the description of the motion of the parts of the automata in terms of 'potentiality' (δύναμις) and 'actuality' ('ἐνέργεια') in Arist. *GA* 734b10-13.

I.7 [4.22-6.1] **ἐκάλουν... θαυματουργούς**. For the inclusion of automata-makers (or automata-making) in the category of wonder-working, cf. the classifications of mechanics found in Papp. 1024.12-1026.4 and Procl. *in Euc.* 41.3-18 (Introduction, pp. Ixvii-Ixix). The term θαυματουργός nowhere else refers to makers of devices, and in fact in Pappus (*Syn.* 1024.25) and Philoponus (*in GA* 77.16, 77.21, 77.23-4, 77.27, 78.17) it is replaced, respectively, by θαυμασιουργός and θαυματοποιός. Berryman (2009: 50) points out that the latter terms are commonly used in late Greek to refer to ‘makers of theatrical devices’, but θαυμασιουργός is found only in Pappus in this sense (and elsewhere only at Eust. Antioch. *Engastr.* 15.2 and Georg. Torn. *Or. Georg. Xiph.* 2.7). (Berryman 2009: 53 n. 136 erroneously refers to Francis 1995 for details on the use of θαυμασιουργός to denote sorcerers and wonder-workers; his study focuses instead on the word θαυματοποιός and its derivatives.) Another term employed in connection with mechanics, and one which carries associations with trickery and magic, is μαγγανάριος (Papp. 1024.14 and 1028.16; Hultsch 1877: 118).

I.7 [6.1-2] **τὸ ἐκπληκτον τῆς θεωρίας**. For the expression, cf. I.1 [2.5] with note ad loc.

I.8 [6.4] **ἐκθέμενοι... ἡμᾶς**. I follow Schmidt in retaining the manuscript reading ἐκθέμενοι. H. Schöne’s conjecture ἐκτιθέμενοι is tempting but unnecessary. The aorist participle may simply express a logical rather than a temporal anteriority. For ἐκθέμενος as denoting time, cf. *Dioptr.* 190.22 and *Metr.* 126.9 (both accompanied by πρότερον).

The most fitting interpretation is one that reads γε as emphatic (‘my own complex scenario’, Murphy 11) rather than limitative (‘Darstellung... welche wenigstens nach unserer Meinung mannigfaltig ist’, Schmidt 343); on emphatic γε, cf. Denniston, *GP* 115-40. The particle is altogether omitted in translation by Baldi 17^r (‘dispositione varia secondo noi’) and Couture 244 (‘certa [?] quam elegimus dispositione’).

I.8 [6.4-6] **ἥτις... διατίθεσθαι**. Brinkmann proposed emending διαθέσει to προθέσει, citing I.2 [2.13] (τὴν προκειμένην πρόθεσιν) in support. This emend-

ation is unnecessary and arbitrary. Hero's point here is obviously to stress the scenic flexibility of his configuration; see note on I.7 [4.20-2].

I.8 [6.7-8] **ἐν δὲ... γράφομεν.** I adopt Schmidt's tentatively proposed emendation of γράφομεν to γράψομεν. This slight emendation is justified by Hero's reference to the 'following book' (τῷ ἑξῆς). In addition to the passage cited by Schmidt in his app. crit. (*Spir.* 28.13-14), cf. esp. *Bel.* 112.8 (ἑξῆς καὶ τὰ μέτρα ὑπογράφομεν) and *Metr.* 46.20-1 (ἑξῆς δὲ περὶ τῶν ἰσοπλεύρων τε καὶ ἰσογωνίων εὐθυγράμμων γράψομεν).

II [6.9-14.16] *Constructional preamble*

Before detailing the construction and operation of the mobile automaton, Hero sets out a series of conditions for achieving mechanical success, each of which is introduced by δεῖ (II.1, 2^{bis}, 3, 4, 6, 8, 10, 11^{bis}, 12) or δεήσει (II.2, 4). There are concerns with stability and weight distribution (II.1, 8); concerns with materials and their properties (II.2, 3, 5-6, 9); concerns with (mechanical) implements and their basic arrangement, with recurring emphasis on cords (II.4-5, 7-8, 10-11); concerns with friction (II.1, 4) and jamming (II.4 σφίγμα, 11), and with some of the principles underlying (different types of) motion (II.7-10); see Cambiano (2011: 31-2 with n. 13). Despite the relative lack of (interest in) constructional details, much of what comes later in the treatise (especially, but not exclusively, in BOOK ONE) relies heavily on the information contained in this preamble. Cambiano (2011: 31) argues, somewhat tentatively, that the use of the future form δεήσει (but cf. also II.4 ἔσται, 5 ἔσται, ἑάσομεν, λήψεται, ἀποκόψομεν, 11 λήψεται, 12 ἀναστρέψεται) suggests that Hero's preliminary instructions presuppose the absence of an already constructed prototype, but the claim that the mechanical components will have to be lubricated (II.4 καὶ ἔλαιον... ταῦτα) clearly implies a completed device (as also recognised by Cambiano 2011: 32). In the concluding paragraph (II.12), Hero, by creating a link back with I.8, re-affirms the superior aesthetic (cf. χαριεστέραν... διάθεσιν) and mechanical status of his own model over the ancients.

II.1 [6.9-13] **Δεῖ δὲ πρῶτον... ἐπινεύουσιν.** The carefully balanced and repetitive structure emphasises the significance of the characteristics of the ground and, in

particular, their role in averting potential stability issues. Note especially the repetition of μήτε and the almost chiasmic relationship between καταδύνωσι πιεζόμενοι and βιαζόμενοι... ἐπινεύωσιν (with a contrasting pair of phrases symmetrically attached: πρὸς ἀνάβασιν... εἰς τὸ ὀπίσω).

The ideal ground surface is likely to be paved with stone slabs: cf. Sor. *Gyn.* 2.44.2 στερεὸν δὲ καὶ ἀπόκροτον τὸ ἔδαφος, ὥς ἂν κατὰ τὸ πλεῖστον λίθοις ἐστρωμένον, where the phrase λίθοις ἐστρωμένον seems to be used instead of λιθόστρωτον, a late term usually denoting paved streets (on which, see Lolos 2003: 161-2). For ὁμαλός as synonymous with ἴσος, cf. S.E. *M.* 3.95-6 τὸ ἔχον ἐξ ἴσου τὰ μέρη κείμενα, τουτέστι τὸ ὁμαλόν· οὕτω γοῦν τὸ ἴσον ἔδαφος καλοῦμεν ἀντὶ τοῦ ὁμαλόν'. The flatness and evenness of the surface serve not only to prevent overload and loss of equilibrium but also to minimise friction.

II.2 [6.14-15] ἐὰν δὲ μὴ... διατιθέναι. A similar point about the need to compensate for uneven ground is made by [Apollod.] *Poliarc.* 173.9-12 (where a siege tower is provided with a separate base, ὑπόθημα); on this passage, see the brief comments of Whitehead (2010: 119).

I follow Schmidt in emending the nonsensical ἀποθώσαντας (**AG**) to ἀπορθώσαντας. In support of this emendation, Schmidt (app. crit. ad loc.) quotes Papp. 166.2 (τύμπανον πρὸς κανόνα ἀπορθωμένον), but cf. also *Spir.* 204.5, where the verb refers to evening out a surface. In his app. crit. Schmidt tentatively suggests adding <ἀκλινεῖς> before the participle, but this supplement seems somewhat redundant in the context. The participle ὑποθήσαντας ('having placed under') which the second hand of **M** wrote in the margin is tempting, especially in light of Ps.-Apollodorus' usage of ὑπόθημα, but would probably require a dative or ὑπό + accusative (perhaps something like ὑποθήσαντας τῷ αὐτομάτῳ or ὑπὸ τὸν αὐτόματον). Prou's ἀπωθήσαντας ('having thrust away', 'having pushed back') is not only implausible, but also contradicts the statement that the boards should be placed on the floor.

II.2 [6.15-17] ἐν αἷς... κυλίεσθαι. For the use of railways in theatrical settings, see Introduction, pp. lxxvii-lxxviii. (Prou 143-4 was naïf enough to think that the system described here had been invented by Hero.) There is no need to emend ἐν

to ἐφ' (Prou). Hero uses ἐν + dative in the same sense ('on', 'over') at XXV.7 [90.3-4] (ἐπ' Prou); but cf. also *Bel.* 105.4 (ἐν τῇ σανίδι).

The adjective ἐφηλωτός, formed from ἐφηλόω (ἐπί + ἥλόω, 'nail on'), is a *hapax legomenon*. Baldi 43^r n. 10 corrected the manuscript reading at his disposal (it is unclear whether he found διεφηλετών or διεφηλητών, as he mistakenly cited both) to διεφηλωτών, probably intending διεφηλωτός (but neither διεφηλωτός nor διεφηλόω is ever attested). It is difficult to see how such a reading, if acceptable, could make sense grammatically, since it has the disadvantage of eliminating διά and making the genitive διεφηλωτών depend on σωλήνες ('canaletti di regoletti imbroccati', Baldi 17^v).

II.2 [6.17-18] **δεῖ δὲ τὰ... ξύλων.** Hero does not specify here the kind of wood to be used, but later on he mentions fir (XXVI.2 [90.17]). (The use of lightweight wood is not limited to mobile automata: XXIII.1 [74.7].) Other woods, such as cedar and pine, may have been a viable alternative (Thphr. *HP* 5.7.1, on ship-building), although fir has the advantage of being lighter (Thphr. *HP* 3.9.7); see Meiggs (1982: 118). For a contrast between 'sturdy' (εὖτονα) and 'light' (κοῦφα) wood, cf. *Bel.* 102.5-7 (where the latter is recommended for components not subject to wear). This contrast is reminiscent of Bito's more explicit instructions: ὅσα γὰρ εἰς τὰ ἐπιμήκη καὶ τὰς σανιδώσεις, ἥτοι πεύκινα ἢ ἐλάτινα ἢ πιτύινα· ὅσα δὲ εἰς τοὺς ἄξονας καὶ τροχούς, δρύϊνα ἢ μελέϊνα, τὰ δὲ αὐτὰ καὶ εἰς τοὺς κανόνας καὶ τὰ ὑποστυλώματα (*Constr.* 52.3-5).

II.2 [6.18-8.2] **καὶ ἐξ... γένηται.** 'Le caisson roulant doit être du *moindre poids possible*, afin de ménager l'effort moteur' (Prou 159). Lightness of construction (to paraphrase Prou's words) provides mechanical advantage as it lessens the effort required to overcome the weight of the device, the forces of inertia and friction (see Pauwels 1980: 149). The amount of friction depends, in fact, on the load applied to the bearings. On the different types of bearing, see note on II.3 [8.5-7].

II.3 [8.3] **ὅσα... ποιεῖται.** I follow Brinkmann in retaining the manuscript reading ὅσα and emending ποιεῖσθαι to ποιεῖται because a finite verb is needed. Schmidt (ὅς' ἂν... ποιῇται) unnecessarily gives the text an indefinite sense (but strangely

he does not emend the following κινεῖται to κινῆται). For the phrasing, cf. XI.8 [40.6].

II.3 [8.4] **ἔντορνά τε ἀκριβῶς**. Perhaps a dim echo of Arist. *Cael.* 287b15-16 κατ' ἀκρίβειαν ἔντορνος [*sc.* ὁ κόσμος], although the unusual adjective ἔντορνος (ἐν + τόρνος) is used elsewhere to denote round bodies which are turned on the lathe: Pl. *Lg.* 898a4-5 τῶν ἐντόρνων... κύκλων, 898b2 σφαίρας ἐντόρνου; cf. XXVI.2 [90.19] (πυρηνίδια), Papp. 1102.13 (τύμπανα) and *DGE* s.v. 1. The adjective/adverb combination ἔντορνος ἀκριβῶς is found in a theologico-cosmological context at Bas. Caes. *Hom. in Hex.* 3.4 (argument against the sphericity of the heavens). Given Hero's insistence throughout the text on the use of the lathe (XI.2 [36.9-10], [36.12-13], XXVI.7 [94.20], [96.2]; cf. XVI.2 [54.16] ἐντετορνεύσθω σωλήν), it is best to retain the original sense of ἔντορνος ('lathe-turned'): cf. Baldi 17^v ('tornite') and Couture 245 ('tornatas'). Schmidt 345 ('recht rund') and Murphy 12 ('perfectly round') translate more loosely. The adverb ἐντόρνως is attested only once (cf. app. crit. to XXIII.3 [76.4]), but, judging from its context, it appears to be a late insertion.

II.3 [8.4] **περὶ δὲ κινεῖται**. The subject of κινεῖται, which must be supplied, is the preceding ὅσα (thus Couture 245, Schmidt 345, Murphy 12); *contra*, Baldi 17^v, who unwisely construes περὶ as absolute and δὲ as the subject of the relative clause.

II.3 [8.5-7] **οἶον... χαλκῶς**. Two types of axle configurations, using different bearings: κνώδακες and χοινικίδες (even though the latter configuration is not mentioned anywhere else in the treatise in connection with the figures). Recent investigations by Keenan-Jones-Ruffell-McGookin (2016: 174-79, 181-2) have shed light on the characteristics of these bearings as emerging from a variety of sources. While the κνώδαξ is a thin, probably pointed pivot (either fixed or rotating within its socket, as in the *Automata*: **Fig. 3**), the χοινικός, cylindrical in shape, generally denotes the hub (as at XI.3 [36.15], XI.4 [36.24], XI.7 [38.15], [38.17], [38.22], in the context of snake-like motion) or the collar of a wheeled axle (but it usually refers to hinge sockets in inscriptions); it, too, can be either fixed (as in the present passage) or rotating (its rotation generally being inde-

pendent of the movement of the axle). The choice of iron over bronze (on which, cf. Orib. 49.3.5-6) and the physical characteristics of the κνώδαξ provide the former type with high wear resistance and a low coefficient of friction. For Hero's predilection for κνώδακες over χοινικίδες, cf. XI.8 [40.3-7].

As for ἐμπυελίς ('socket'), the term is not attested outside Hero. It appears to be used quite interchangeably with πυελίς (V.3 [20.20]; cf. [Apollod.] *Poliorc.* 148.8) and ἐμπυελίδιον (X.1 [32.21] and [32.22], XI.9 [40.10], XXVI.2 [90.19]).

II.3 [8.8] συνεσμηρισμένας. In his app. crit. Schmidt notes that the second hand of **T** corrects σμηρισμένας to συνεσμηρισμένας. I cannot find the presence of two different hands here, even though the first five letters of the word appear to be written in lighter ink. Even assuming that a correction occurred, it is hard to say whether the original reading was σμηρισμένας or, rather, μηρισμένας.

συσμηρίζω is a technical term found only in Hero. It is much more frequent than its uncompounded form σμηρίζω (17 occurrences against 2), which is likewise unattested elsewhere. Of uncertain origin (perhaps derived from σμήω/σμάω, 'rub', 'wipe'; cf. Frisk, *GEW* s.v.), σμηρίζω is explained as meaning 'to smooth so as to make an air- or watertight joint' (cf. *Spir.* 78.2-4). The compound form consistently refers to two tubes (or two cone-shaped containers: *Spir.* 186.17-18) fitted one inside the other (cf. XIII.3 [46.8]), the whole structure being called σμήρισμα (e.g. *Spir.* 54.11) or σμηρισμάτιον (e.g. *Spir.* 54.1); see LSJ s.v. σμήρισμα I and Drachmann (1948: 50). It is surely far-fetched to posit a relationship between σμήρισμα and μήρυμα, as does Meister (quoted in Schneider 1801: 120-1); on the latter term, see note on II.11 [14.4].

II.4 [8.9-11] καὶ ἔλαιον... γένηται. On the use of oil as lubricant, cf. Vitruv. 10.7.3 *supernis in modiolis emboli masculi torno politi et oleo subacti*. Unfortunately, neither Vitruvius nor Hero specifies the type of oil to be employed, but we can perhaps rule out olive oil (*pace* Murphy 40 n. 3) because of its superior quality (see Harris 1974: 33) – unless, of course, the cheapest and lowest grade (ἔλαιον χυδαῖον) was utilised (on qualitative distinctions for oil, see Mayerson 2002: 101-5, 108-9). Note that the term ἔλαιον has a broad semantic spectrum and is best understood in the generic sense of '(vegetable) oil' when occurring unqualified (Mayerson 2001: 115-17, drawing on Sandy 1989: 18-24).

R. Schöne's deletion of the first πάντα (accepted by Schmidt) is unnecessary, since the expression κατὰ πάντα τρόπον makes good sense taken together with the following εὐκύλιστα ('easy to rotate in every possible way', i.e. 'in every possible direction'; cf. 'in tutto, e per tutto', Baldi 17^v). Nor is it necessary to emend τρόπον to τόπον (Brinkmann), as that would imply that the implements could be made to rotate easily either in their entirety (κατὰ πάντα τόπον, cf. Hero, *Spir.* 12.19) or in part. R. Schöne compared Hero's words with Ph. *Parasc.* 88.32 and 96.4, where the common phrase κατὰ τρόπον ('fitly', 'duly', as with LSJ s.v. τρόπος II.4.b) is used. To these Schmidt (app. crit. ad loc.) added Hero, *Bel.* 73.8 and *Dioptr.* 290.12 (context corrupt), but he failed to notice that the expression κατὰ πάντα τρόπον occurs elsewhere in the corpus (*Bel.* 102.5). Perhaps part of the problem perceived by R. Schöne and later by Schmidt has to do with the indeterminate pronoun ταῦτα, but even assuming it does not refer to all of the components mentioned at II.3 [8.5-7], κατὰ τρόπον is not necessarily better than the transmitted text, which, in any case, implies proper rotation. Untroubled by any such concerns, Couture 245 and Murphy 12 omitted translating these words.

Among the main manuscripts, only **G**, **M** and **T** have πάντα between κατὰ and τρόπον. **A**, instead, has πάντ (written as παν^τ, which I have reproduced in my app. crit. ad loc.). The scribe of **A** commonly employs two vertically aligned dots in combination with τ ('dotted τ') to express τα (on this abbreviation, see Allen 1889: 3-4), but in this case he seems to have forgotten to write them down.

II.4 [8.12-15] δεῖ δὲ καὶ... κατεστάθηναι. Because what is sought is non-elasticity (rather than 'constant tension', as believed by Murphy 40 n. 4), cords are made of material other than sinew (II.6 [10.4-5]), possibly hemp or flax (for the latter, see already Murphy 40 n. 3). Non-sinew cords need to be pre-treated (or 'pre-tested', as at II.5 [8.21]) like sinew spring-cords but, unlike the latter, their pre-stressing greatly reduces, if not removes, springiness (the whole process, which is performed manually, is described at II.5 [8.16-10.1]; cf. *Dioptr.* 254.13-15 and 262.13-14, passages in which a cord that has been (pre)-tested is defined in terms of its ability to maintain a constant length); on the stretching of spring-cords (with or without the aid of an instrument called ἐντόνιον), cf. Ph. *Bel.*

61.6-16, Vitr. 10.12.2, Hero, *Bel.* 98.10-99.1, 107.10-108.7. See also note on II.6 [10.7-8].

There is a logical leap from the considerations of II.3-4 [8.3-12] to the statement that the cords are used εἰς ταῦτα (εἰς clearly expresses purpose since it depends on προσχρώμεθα and cannot be taken as indicating direction: cf. ‘on these moving parts’, Murphy 12). Even though the function and the positioning of the cords have not yet been discussed at any length (the first discussion of these matters occurs at II.7 [10.11-14]), the reader can easily fill the gap in the argument by taking ταῦτα to refer to the movements effected by means of the bearings.

II.5 [8.16-17] βαλόντες... εὖ μάλα. If we accept the manuscript reading λαβόντες, we have to construe περί with διατείναντες (which is quite uncommon) and delete the comma after πασσαλίσκους. In his app. crit. Schmidt tentatively proposed περιβαλόντες on the basis of V.4 [22.10] and VI.2 [24.11], but H. Schöne’s uncompounded form has the advantage of being easier to explain palaeographically, i.e. through simple letter inversion. The verb βάλλω is also used in a comparable way at *Mech. Frag.* 3.2 = Papp. 1132.8 ὄπλον βάλλοντες περὶ αὐτό [i.e. ξύλον]. It is unnecessary to join the two participial clauses with a coordinating καί (Diels) since asyndetic coordination is not unknown to Hero: see, for instance, XI.3 [36.17].

II.5 [8.19] κηρὸν μετὰ ῥητίνης. The same mixture is used for gluing loops of cord onto the axle that imparts movement to the doors of the πίναξ: XXIII.7 [78.13]. Commenting on the latter passage, Prou 224 n. o identified this compound with the so-called ζώπισσα (‘live pitch’, i.e. pitch and wax from the hulls of ships). It is not clear whether Hero’s compound is ζώπισσα or simply pitch and wax (no salt added). Note, however, that Hero is referring to wax mixed with pitch as opposed to pitch mixed with wax (cf. the definitions of *zopissa*/ζώπισσα by Plin. *Nat.* 16.56 and Dsc. 1.72.5). This could perhaps be taken as an indication that the two substances were mixed together in different proportions. At any rate, the compound clearly serves here as a bonding agent. Similarly, resin (but not wax, as far as evidence goes) was probably used in the pre-

paration of hair-rope for catapult springs (Marsden 1969: 76 n. 2, on Plb. 5.89.9; cf. also Landels 1978: 111, although the passage is left unspecified).

II.5 [10.1-3] ἦ... εὖρωμεν. The scribe of **A** has corrected ἦ to what seems to me to be one of the abbreviated realisations of καί (something like κ'), one that is frequently confused with ἦ. Schmidt's app. crit. does not record **A**'s correction, possibly because it closely resembles ἦ. The confusion between the two conjunctions might explain why the corrected reading was not recognised as such by the scribes and, consequently, was not copied in any other manuscript. At any rate, such a correction (already proposed by R. Schöne) does not seem quite right, since Hero is envisaging a scenario in which the procedure he has just described (II.5 [8.16-10.1]) does not yield the most desired results. So, the words ἦ πάλιν correctly introduce an alternative; cf. I.4 [4.8] and *Metr.* 4.29-6.1.

The manuscripts have ἐξαρθήσαντες in place of ἐξαπτύσαντες (Brinkmann and H. Schöne; also adopted by Schmidt), but this is an error owing to iotacism. The verb ἐξαπτύω (used once at XXVI.6 [94.10]) would require both a direct and an indirect object, and the phrase ἐξαρθήσαντες τὸ αὐτόματον ('having hung the automaton') would hardly make sense in the context. Baldi 17^v, apparently followed by Couture 245, translated *ad sensum* ('dopo averle attaccate [sc. le corde] alla Machina se Movente') by turning the direct object into the indirect object and by supplying 'cords' as the direct object of ἐξαρθήσαντες. In support of his correction, Brinkmann adduced some examples of Philo's use of the verb ἐξαπτύω (*Bel.* 54.24) and its derived nouns ἐξάρτυσις (*Bel.* 56.29, 57.28, 61.6) and μετεξάρτυσις (*Bel.* 58.2 [*hapax*]; but LSJ s.v. doubt its authenticity), all referring to the process of readying, that is, stringing a catapult (for ἐξαπτύω in this sense, cf. also Ph. *Bel.* 54.19, 61.7, 61.8, 61.20, 66.17). Although the verb ἐξαπτύω does not appear elsewhere in the Heronian corpus, it accords well with Hero's tendency to make comparisons with catapult technology (II.6 [10.6-7], XIII.9 [50.11]). On the confusion between ἐξαρθάω and ἐξαπτύω, cf. also the variant readings at A. *Pr.* 711.

I adopt Schmidt's emendation παρεκτεταμένην. The only other plausible reading is **G**'s παρεντεταμένην, but the verb παρεντείνομαι is never attested in Hero or in other mechanical writers. Schmidt rightly bases his conjecture on II.6 [10.4]. Cf. also Ph. *Bel.* 65.30 (the stretching of a spring-cord).

II.6 [10.4-8] **νευρίῳ δὲ...δῆλον.** This passage has attracted interest since the sixteenth century. Baldi 43 nn. 12-13 was the first to discuss the term ὕσπληγξ (or, more commonly, ὕσπληξ, as in LSJ s.v. ὕσπληξ 1) within the context of the *Automata*, albeit without being able to explain the comparison drawn with catapult technology. After enumerating three meanings of the term, that is, ‘whip’ (‘flagello’, ‘sferza’), ‘cord serving as a barrier in footraces’ (‘la corda, che si stende inanzi à chi corre il palio’) and ‘ox-’ or ‘pig-goad’ (‘pongetto’, ‘stimolo de’ buoi’, ‘sferza da porci’), he observed (n. 12) that the word here means ‘wooden bar’ (‘righetta di legno’), because this is the sense in which it is employed (mostly in its derived form ὕσπλήγγιον) in Hero’s description of the mechanism controlling the movement of the Greek sailors’ arms (cf. esp. XXIV.4 [82.13]; on the mechanism more generally, see XXIV.3-5 [82.7-4.7]; **Fig. 29**). Baldi’s notes 12-13 have been recently examined by Micheli (2005: 254-7), who, following in the steps of Prou 177-8, has elucidated (if only partially) the mechanism of Hero’s ὕσπληγξ, a mechanism which finds no practical application in the treatise. Micheli (2005: 255-7 with nn. 30, 37, 39) makes the following points: first, ὕσπληγξ and ὕσπλήγγιον have different functions, the former being a ‘bar’ powered by twisted sinew (ἡμιτόνιον would denote a single bundle of sinew, as at Hero, *Bel.* 83.4, and not half of it, as intended by Ph. *Bel.* 68.24-6; see also Marsden 1969: 17; 1971: 49 n. 18) like the arm (ἄγκών) of the torsion catapult, the latter an ‘axle’ which is repeatedly set in motion by a wheel (ἄστερίσκος), and hence works in a similar fashion as an escapement (see already Preus 1983: 102); second, the quasi-escapement mechanism of the ὕσπλήγγιον suggests that the torsion engine comprising the ὕσπληγξ was attached to a toothed device that served as a flywheel; third, the only other attestation of ὕσπληγξ-powered automata is Arist. *MA* 701b2-3; fourth, more importantly, Baldi’s notes are misleading or pointless, all the more so since the meanings of ὕσπληγξ listed by the Renaissance scholar are not relevant to the understanding of Hero’s text.

Two interrelated questions arise from these observations: ‘In what sense does Hero use the terms ὕσπληγξ and ὕσπλήγγιον?’ and ‘What is the relationship between these two devices?’. Prou 177-8 has to some extent already answered these questions by saying that the original mechanism of the ὕσπλήγγιον, involving torsion springs, was replaced by a more effective and safer counter-

weight mechanism, while still retaining its ancient name (there follows a brief discussion of the term ὕσπληξ employed in the senses of ‘barrier’ and ‘swing door’, but no source is cited in support of the latter). The hypothesis that a different mechanism was used (by Hero?) at an earlier stage, together with the incompletely revised state of the text (on which, see Introduction, pp. cxvii-cxviii), would in effect explain the reference to a missing passage in the treatise (ὥς ἔξῃς ἔσται δῆλον), a reference which can hardly point to Hero’s own *Belopoeica*, as believed by Schmidt 347 n. 1.

Now, if we look back at the term ὕσπλη(γ)ξ, we see that it may refer, among other things, to a movable barrier controlling the start of a race (LSJ s.v. ὕσπληξ 3). In the wake of the discovery (1970) of a Panathenaic amphora which dates to 344/343 BCE (stored in Athens, Third Ephoreia of Classical Antiquities, inv. no. A6374) and which shows on its reverse such a starting system, Valavanis (1999: esp. 35-44) reconstructed a new type of ὕσπληγξ (for a detailed analysis of the reverse of the amphora, see Valavanis 1999: 20-31, with Figs. 19, 20-3, 25), as compared to the one discovered and reconstructed by Brooner (1973: 49-52) at Isthmia. Valavanis (1999: 32-41, 51) demonstrated that the newer type of ὕσπληγξ, mainly consisting of two poles with a cord or wooden rod stretched between them, owed its design and technology to the advent of torsion artillery machines in the fourth century BCE, a fact which is reflected in the shared terminology used to describe certain elements of these devices (for example, the poles of the ὕσπληγξ are called ἀγκῶνες, cf. *ID* 1400.9 and 1409 Ba col. II 43; a word of caution against making too much of such terminological overlaps has been offered by Miller 2001: 53 n. 125). So, Hero’s comparison between the ὕσπληγξ and the catapult arm (ἄζων unmistakably signifies the ἀγκών of a catapult, as is made clear by the variant reading ἄγκων [*sic*] of manuscript **Pe**, possibly a supralinear gloss rather than a correction), which has already been highlighted by Valavanis (1999: 33 n. 95), indicates that Hero is deliberately using the term ὕσπληγξ to refer to a mechanism operating substantially in the same way as the torsion system depicted on the Panathenaic amphora. Contrary to what has been argued by Micheli (2005: 255-6), therefore, what Hero has in mind is not simply a ‘bar’ but a torsion engine in its entirety (why else, then, paraphrase ἀγκών as ὁ ἄζων... ἡμιτονίῳ if not to designate the whole arrange-

ment?). Furthermore, despite Baldi's erroneous interpretation, not all of the meanings quoted by him are, in some way or other, irrelevant.

Moving on to consider the relationship between ὕσπληγξ and ὕσπλήγγιον, it seems unquestionable that the latter originally derived its name from the resemblance it bore to the starting barrier rather than from the fact that, as suggested by Preus (1983: 103), a lever such as that may sometimes have been activated by a 'small pig whip' (LSJ s.v. ὕσπληξ 6). This last supposition is based on the understanding of the word ὕσπληγξ at II.8 [12.1] and [12.3] as referring to 'twisted cords', in accordance with LSJ s.v. ὕσπληξ 2 (so also Schmidt 347; Murphy 40 n. 4, in turn, wrongly regards ὕσπληγξ as a common word for the catapult spring), but it is difficult to see why the term should have a different sense from that in which it is used in all previous occurrences, including II.6 [10.9] (mentioned together with the counterweight, as at II.8 [12.1], where τάσις ὕσπληγος may very well refer to the tension controlling the whole mechanism). The connection between the two devices is brought out most clearly at XXIV.4 [82.19-20] **καταπεσεῖται** [*sc.* τὸ ὕσπλήγγιον] ἐπὶ τὸν ἐπίουρον ἐπισπωμένης τῆς λείας καὶ **ψόφον** ποιήσει, because ancient descriptions of the ὕσπληγξ include mention of its (downward) motion (cf. esp. Lucianus, *Cal.* 12 τῆς ὕσπληγος... καταπεσοῦσης) and of the noise produced when its poles were pulled down to the ground (cf. *AP* 11.86.3 ὁ ψόφος ἦν ὕσπληγος ἐν οὔρασι, also quoted by Plu. *Praec. Ger. Reip.* 804e); see Valavanis (1999: 5 with nn. 28 and 30), from whom I take the non-Heronian references. However, if Hero's quasi-escapement ὕσπλήγγιον maintains some links with the automatic ὕσπληγξ, it does not necessarily follow that the particular type of ὕσπληγξ referred to in our passage should be provided with a flywheel to reduce the speed at which the sinew spring-cords would have been released. What, at least, emerges from Valavanis' (1999) investigations is that rollers could be used to ease the movement of the cords (starting system of Kos, p. 141), but nothing more than that.

Finally, the more general implication of all this is that Hero's ὕσπληγξ as reconstructed here cannot be straightforwardly compared with the first of the two mechanisms hinted at by Arist. *MA* 701b2-10:

ὥσπερ δὲ τὰ αὐτόματα κινεῖται μικρᾶς κινήσεως γενομένης,
λυομένων τῶν στρεβλῶν καὶ κρουόντων ἄλληλα τῶν ξύλων,

καὶ τὸ ἀμάξιον (ὁ γὰρ ὀχούμενος αὐτὸ κινεῖ εἰς εὐθύ, καὶ
 πάλιν κύκλῳ κινεῖται τῷ ἀνίσους ἔχειν τοὺς τροχοὺς· ὁ γὰρ
 ἐλάττων ὥσπερ κέντρον γίνεται, καθάπερ ἐν τοῖς κυλίνδροις),
 οὕτω καὶ τὰ ζῷα κινεῖται. ἔχει γὰρ ὄργανα τοιαῦτα τήν τε
 τῶν νεύρων φύσιν καὶ τὴν τῶν ὀστέων, τὰ μὲν ὡς ἐκεῖ τὰ
 ξύλα καὶ ὁ σίδηρος, τὰ δὲ νεῦρα ὡς αἱ στρέβλαι· ὧν λυο-
 μένων καὶ ἀνιεμένων κινουῦνται.

Just as automatic puppets move as a result of a small movement, when the cords are released and the pegs strike one another, and just as the small cart <moves> (for he who rides <in it> sets it in motion straight ahead, and again it moves in a circle because it has unequal wheels: for the smaller acts as a centre, just like in the cylinders), so too do animals move. For they have organs so constituted, both sinews and bones, the latter <being> like the pegs and the iron therein, the sinews like the cords; when these are released and slackened, <the animals> move.

I follow here the text of Nussbaum (1978) rather than that of Jaeger (1913), except for τροχοὺς (line 5), which Nussbaum (1978: 43) has misprinted as τρόχους (same error in Nussbaum 1976: 146). The textual problems of the passage, which had previously been ignored by Jaeger (1913), have been discussed by the most recent editor in Nussbaum (1976: 150-2), with a review of the solutions proposed and interpretations offered by other scholars. The text adopted by Micheli (2005: 256 n. 34) differs somewhat from Nussbaum's (1978), but the differences between the two texts do not affect the present line of argument. (It is not clear to me whether Micheli accepts Forster's addition of τὸ before ὀχούμενον [codd. plerique : ὀχούμενος *b*₁] at line 4, because of his inconsistent use of round brackets; cf. already the text cited in Micheli 1998: 458 n. 146.) Textual problems aside, Aristotle's αὐτόματα ('automatic puppets') cannot easily be made to correspond to any of the devices described by Hero. Micheli (1998: 458-9), for example, reads the Aristotelian passage through the lens of Hero's *Automata*, but his analogy between the puppets and the apparatuses constituting the Dionysian arrangement lacks stringency (such analogy forms the basis of his more recent argument, as laid out in Micheli 2005: 257). Berryman

(2009: 73), in turn, suggests that the starwheel and ὑσπλήγγιον assembly of XXIV.4-5 (why would the moving arm belong to 'a figure of Hephaestus'?) fits well with the Aristotelian lines, but unfortunately she does not elaborate further. We can at least infer from her diagram of the Heronian device (Berryman 2009: 74 Fig. 2, based on Schmidt 425 Fig. 103a) that she takes the ξύλα of line 2 to correspond to 'pegs' attached to the starwheel (cf. also Berryman 2009: 74 n. 75), but the word used by Hero, ἀστερίσκος, rather leads one to imagine a toothed, gear-like wheel. Moreover, the starwheel's projections, whether they be pegs or teeth, strike not against one another (as Aristotle's 'pegs' do) but against the ὑσπλήγγιον. From a different perspective, Nussbaum (1976: 149-50) tentatively equates the iron component mentioned at line 8 (ὁ σίδηρος) with the axle connecting the wheels of the mobile automaton, but the wheel axle is nowhere said to be made of iron. On the other hand, she observes (p. 149) that Hero's figures (which she erroneously considers puppets; cf. also Nussbaum 1978: 347 n. 5), unlike most of the automatic marionettes mentioned in ancient sources, cannot be made to move their limbs by means of a mechanism consisting essentially of interlinking pegs and cables (at least following Nussbaum's reconstruction, but other reconstructions are possible: see Introduction, p. lxxxv n. 158). [Arist.] *Mu.* 398b13-19, one of the passages cited by Nussbaum (1976: 147-8) to support her reconstruction of the puppets' mechanism, distinguishes between two categories: μηχανοτέχναι ('machine workers') and νευροσπάσται ('puppeteers'); the former initiate automatic sequences of movements using the machine's single release-mechanism (διὰ μιᾶς ὀργάνου σχαστηρίας), whereas the latter make their puppets move automatically by pulling a single rope (μίαν μήρινθον ἐπισπασάμενοι). Hero's mobile automaton is activated by pulling a cord (cf. IX.5 [32.10-12]), just like a puppet, but all subsequent movements, including those of the figures, occur through self-triggered activation of regulatory devices (cf. esp. XIII.9 [50.12-14] ὅπως τῆς σχαστηρίας ἀπολυθείσης ἀπό τινος σπάρτου τὸ βάρος κατενεχθὲν ἐπιστρέψῃ τὸν τε Διόνυσον καὶ τὴν Νίκην), which are indeed missing in Aristotle's puppets, as noted by Preus (1983: 100).

Returning to the topic of the ὑσπληγξ, the term, as pointed out by Micheli (2005: 257 n. 35) himself, is absent in the Aristotelian passage, and it is hard to accept his interpretation of the words λυομένων τῶν στρεβλῶν (which he translates as 'corde attorcigliate che si sciolgono') as a clear reference to this type of

device. When Nussbaum (1976: 150) compares the arrangement of Aristotle's στρέβλαι (i.e. cords wound around a wheel or roller) with an unspecified Heroian mechanism, she is probably thinking of the ἐξελίκτηρα (first mentioned at V.3 [22.2]; see note on V.3 [22.2-3]), the bobbin attached to the wheel axle and around which the cord is wound, certainly not of the ὕσπληγξ, which, as we saw above, she understands as 'torsion cable' (the lack of any mention of στρέβλαι in the present context excludes the possibility that Hero's ὕσπληγξ was connected to some kind of wheel). To this must be added that the purpose of the ὕσπληγξ as defined at II.6 [10.8-9] seems to be to impart motion to the mobile automaton as a whole, not (or not just) to the figures. There seems to be no reason, therefore, to suppose that Arist. MA 701b3 contains a reference to a ὕσπληγξ-type of engine rather than simply to (torsion?) cables (cf. MA 701b9-10). Hero, after all, remains our only written source attesting to a possible use of the so-called ὕσπληγξ ('trigger board?') as motive force of automata.

II.6 [10.4] οὐδενὶ δεῖ. In his app. crit. Schmidt correctly says that **A**'s οὐδενὶ seems to be a correction. In the wake of the previous editor, I have reproduced the reading of **A** as it is found in the manuscript (cf. app. crit. ad loc.). **A**'s reading before correction is οὐδενὸς δεῖ, with -ὸς being written *in compendio* above the ν. It would appear that the ο has been neatly inked out, and the termination -ι added at a later stage. The scribe did not need to add a grave accent because he had already written one when abbreviating -ὸς. Other manuscripts, such as **G^{ac}** and **T**, have οὐδενὸς ἰδεῖ, probably because the scribe, not recognising οὐδενὶ as a correction, regarded the ι as belonging to the following word (wrong word-division). The scribe of **G**, however, corrects οὐδενὸς ἰδεῖ by replacing the ο with ἰ and deleting ῖ (οὐδενὶς ἰδεῖ). I tentatively take the latter reading to reflect οὐδενὶ δεῖ. The scribe might have thought it sufficient to replace the penultimate letter of οὐδενὸς or simply forgotten to underline the ς.

II.6 [10.4-5] παρεκτείνεται ἢ συστέλλεται. Schmidt's tentative conjecture ἢ is preferable to καὶ. Some manuscripts, including **A** and **M**, write καὶ compendiously (on the confusion between ἢ and the καί compendium, cf. note on II.5 [10.1-3]), and the disjunctive is what we find in parallel expressions, such as Ph. Bel. 68.11-12 ἐπεκτείνειν ἢ συστέλλειν and Hero, *Dioptr.* 254.15 ἐπεκτείνεσθαι

ἢ συστέλλεσθαι. Cf. also Hero, *Spir.* 90.5-7 τῶν συρίγγων ἥτοι λεπτοτέρων γινομένων <***> ἥτοι καὶ παρεκτεινομένων εἰς μῆκος ἢ καὶ συστελλομένων. Here the repeated καί presumably marks an addition to the content of the preceding context (see generally Denniston, *GP* 293), which, although lacunose, can easily be reconstructed: cf. Ps.-Hero, *Spir.* 90.25-7 τῶν συρίγγων ἥτοι λεπτοτέρων γινομένων ἢ παχυτέρων καὶ ἢ παρεκτεινομένων εἰς μῆκος ἢ συστελλομένων (note the anteposition of the first καὶ and the suppression of the second).

II.6 [10.7-8] ὁ ἄξων κατατεταγμένος ἐν τῷ ἡμιτονίῳ. On the referential meaning of this phrase, see note on II.6 [10.4-8].

The reading κατατεταγμένος, which is transmitted by **AGT**, is surely genuine, because it describes the insertion of the axle (i.e. the arm) through the bundle of sinew. The reading of **M** (κατατεταμένος), by contrast, is probably a mistake owing to the omission of γ. A number of manuscripts (**Ab**, **Ac**, **Bb**, **La**, **Lc**, **Ld**) have ἐντεταμένος. This can possibly be explained as an erroneous correction of κατατεταμένος made under the influence of the words ἐν τῷ ἡμιτονίῳ. The verb ἐντείνω is, in fact, used several times to denote the act of stretching or stringing catapult springs (Ph. *Bel.* 61.20; Hero, *Bel.* 78.4-5, 99.3, 107.10; cf. Hero, *Bel.* 101.10, 102.1-2; Ph. *Bel.* 58.20 reads ἐκτεῖναι τὸν τόνον, but Diels thought fit to emend the infinitive to ἐντεῖναι: cf. Ph. *Bel.* 58.27 Diels-Schramm), or entire torsion engines (Ph. *Bel.* 56.12, 56.19 and 67.25); hence the name of the so-called ἐντόνιον ('stretcher'), a device used to give tension to the springs: cf. Vit. 10.12.1-2 and, especially, Hero, *Bel.* 107.1-110.3; criticised by Ph. *Bel.* 57.32-58.5 (on this device, see Marsden 1969: 30-1, 42; 1971: 59 Fig. 23). On the stringing of a catapult, see also note on II.5 [10.1-3].

II.6 [10.8-10] πάντα δὲ... μολιβῆς. Of the two power systems (on the ὕσπληγξ, see note on II.6 [10.4-8]), Hero prefers the latter. What appeals to him is perhaps the counterweight's wider applicability. Hero insists (II.8 [12.3-6]) that the movements other than locomotion, too, take place by means of a (single) counterweight. This is ultimately true, even though a secondary counterweight is used to rotate the figures of Dionysus and Nike (cf. XIII.8-9 [50.6-14]). Murphy 42 n. 29 has tentatively wondered whether this secondary counterweight is the addi-

tional counterweight introduced in the two-counterweight configuration (XIX.2 [60.18-19]). This seems to me to be utterly implausible not just because, as Murphy points out, these counterweights are activated by different means, but especially because they are positioned in different places (outside and inside the *σύριγξ*, respectively).

Prou 162 observes that '[p]our réduire le volume de ce contrepoids, on le fabrique *en plomb*, d'un poids total calculé sur l'ensemble des résistances à vaincre, quantité facile à déterminer par l'expérience'. Indeed, the density and the workability of lead (on which, see Nriagu 1983: 59, 256-7; Wright 2005: 235) make it a good choice for a small counterweight, which is made to sink in the limited space provided by the *σύριγξ* (II.8 [12.6-7], V.5 [22.15]). That Hero is well aware of the heaviness of lead is clear from IX.4 [32.3] and XXX.3 [108.2]; cf. also XV.4 [54.6-7].

II.7 [10.11-14] κοινὸν δέ... προσηγκυλωμένην. The cord cannot be 'nailed' or 'riveted' (following the manuscript reading *προσηλωμένην*) to the element being moved, as this would hinder the transmission of the movement. Baldi 18^v had apparently already realised the incorrectness of this reading since he translated it as 'aviluppato' [sc. il capo della corda], thus anticipating Brinkmann's conjecture *προσηγκυλωμένην*. Murphy's translation ('one end attached to each', 12) erroneously conflates the *μὲν* and *δὲ* clauses into one expression. Hero, however, is describing two different modes of attachment ('binding' and 'looping') between the cord and either of the elements. The participle *προσηγκυλωμένην* has been conjectured by Brinkmann, and rightly so, on the basis of two occurrences of *προσαγκυλόομαι* (II.8 [12.4], II.11 [14.8]) and II.9 [12.14-15] (*ἀγκύλη*). If we look closer at the context of II.8 [12.4], we find the same distinction as we have here, but expressed in less abstract terms (II.8 [12.4-6]). Also relevant is the definition of *τὸ κινούμενον* as *ἄξων... περὶ ὃν ἡ σπάρτος περιεΐληται* that immediately follows the present passage.

II.7 [10.15-17] τῷ δὲ ἄξωνι... τροχόν. In one of the main manuscripts (**M**), *ἀπειλισσομένης* is corrected *supra lineam* to *ἐπειλισσομένης* ('twisting', 'being rolled up'), but this correction only indicates that the scribe, perhaps identifiable with the second hand, had a poor understanding of the mechanism whereby mo-

tion is transmitted to the wheel axle (on which, cf. also V.5 [22.15-19], VI.1 [24.4-6], XI.3 [36.15-19]). It is self-evident that, by being pulled by the counterweight, the cord being wound around the axle, and passing through a pulley at the top of the σύριγξ ([V.5] 22.13-14), was unrolled. Here, however, the reader is first presented with the turning of the axle, and then with the unwinding of the cord (τοῦ ἄξονος στρεφομένου καὶ ἀπειλισσομένης τῆς σπάρτου); such a *hys-teron proteron* focuses attention on how the movement is transmitted from the axle to the wheels, thus letting the reader know immediately how the automaton starts moving.

II.7 [10.18] ἐπὶ τὸ ἔδαφος. ἐπὶ is replaced by κατὰ in **M**, whereas it is omitted in **T**. The former reading has better manuscript support (**AG**) and also appears much more frequently in conjunction with ἔδαφος than κατὰ does (both outside and inside Hero's works). There is only one instance in Hero (V.5 [22.18-19]) of κατὰ followed by ἔδαφος, but in that case ἔδαφος appears in the genitive, not in the accusative: the syntagm κατὰ τὸ ἔδαφος is extremely rare, occurring only in late sources (*Hippiatr. Berol.* 129.39.11, *Jos. Genes.* 2.8.34, *Theoph. Cont.* 230.6 and *Paraphr. rec. in Lycophr.* 625). Similarly, all other Heronian occurrences of the prepositional phrase 'on the ground' (II.2 [6.15], XI.9 [40.14], *Bel.* 89.3, *Dioptr.* 202.15-16, 204.12, *Mech. Frag.* 3.1^{bis} = Papp. 1130.11 and 1130.17) have ἐπὶ governing the genitive (cf. also *Ath. Mech.* 30.2, [Apollod.] *Poliorc.* 162.1, 164.3). The preponderance of the genitive in these phrases suggests that we emend τὸ ἔδαφος to τοῦ ἐδάφους, but it is difficult to rule out the possibility that this is merely a semantic equivalence (see generally Bortone 2010: 183-4).

II.7 [10.18-19] τοῖς δὲ... πλινθίον. For a similar expression, cf. XXX.3 [106.20-108.1] περιλαμβάνει [sc. τὸ σανίδιον] τὰς χορδὰς.

The term πλινθίον here, as throughout the rest of the book, denotes the 'base unit' of the mobile automaton (cf. III.1 [14.17] βάσις). Perfectly, or almost perfectly, synonymous with πλαίσιον and πλινθεῖον, it can be used to refer to any kind of 'frame' or, more generally, to any 'rectangular object' or 'figure' (for a review of these terms and their relationships, see Saliou 2004: 187-9). Both Philo (*Bel.* 60.5) and Hero (*Bel.* 81.8), for example, adopt the word as a technical term for the wooden frame of a catapult (see Marsden 1969: 57; 1971: 47-8

n. 16), whereas Bito (*Constr.* 60.1) speaks of *πλινθίων* as a box (perhaps a 'shallow tray', as conjectured by Marsden 1971: 95 n. 48). The word occurs again in the context of stationary automata, where it most certainly designates the frame of the *πίναξ*. Thus, there appear to be two main uses of the word *πλινθίων* in the treatise, both of which are related, though in different ways, to architecture and construction.

According to Baldi 43^r n. 14, the term (which he mistakenly accented on the antepenultimate syllable) is used in architectural contexts of the 'lowest square part of the base [sc. of a column], namely the socle', but his words are more correctly applied to the primitive form *πλίνθος* (cf. LSJ s.v. II.3; but cf. *Didyma* 38.10 [277/276 BCE] for the diminutive *πλινθίς*) and its Latin equivalent *plinthus* (Ionic order: Vitr. 3.5.1-3 and 5.9.4; but cf. Vitr. 3.3.2, where *plinthis* is used twice). What is interesting for present purposes is that this more specialised meaning is thought to have been derived from the meaning of 'building block', 'wall block' (Hellmann 1992: 342, with 'pierre d'assise'), a meaning which in epigraphic sources is attached not just to the word *πλίνθος* (*IG* 1³.474 A col. I 10, 474 A col. I 95, 474 A col. I 104 [Erechteion construction work inventory, 409/408 BCE], *CID* 2.56 col. II C 82 [337/336 BCE] and 2.62 col. II A 2 [335/334 BCE], *Didyma* 102.22), as erroneously believed by Hellmann (1992: 342), but also to its derivatives, such as *ἡμιπλίνθιον* (*Didyma* 99.11-12) and *πλινθίς* (*IG* 2².1668.26, 1668.93 [the so-called Arsenal inscription, 347/346 BCE]). This, together with the alternative designation of *πλινθίων* ('case') as *βάσις* serving as a support for the whole automaton, suggests that Hero's usage is influenced, even if only to a limited extent, by the architectural meaning of the word and its close relatives (in other instances, the words *πλαίσιον* and *πλινθεῖον* have been interpreted as meaning 'stand' or 'socle', but it is more likely that they refer to the frame of a votive offering; see Hellmann 1992: 340 n. 3).

As for the usage of *πλινθίων* in the second part of the treatise, it somewhat parallels the usage of its associates *πλαίσιον* and *πλινθεῖον* in inscriptions, particularly those from Delos. In addition to the more common meaning of 'frame [sc. of a votive offering]' (cf. also *ID* 1443 B col. II 51 and 1446.24 *πινάκιον πεπλαισιωμένον*), both of these words can also refer to the upper frame of a (painted) ceiling coffer (*πλαίσιον*: *IG* 1³.474 B col. I 240-1 and 474 B col. II 246, *ID* 504 A 13, 504 A 15, 504 A 16 [279 BCE]; *πλινθεῖον*: *Didyma* 103 a.36,

IG 11².165.22, 165.32 [Delos, 279 BCE]; Saliou 2004: 188 n. 11 further compares Vit. 9.8.1 *plinthium sive lacunar*); for discussion of the link between Hero's stationary automaton and the tradition of panel painting, cf. note on I.3 [2.17-18]. When Hero instructs the reader to equate the dimensions of the πίναξ and the πλινθίον (XXIII.1 [74.5-7]), therefore, he is talking about the 'skeletal frame' of the whole πίναξ, not about an ordinary 'case' or 'box', as translators have understood the term. This interpretation is further confirmed by another architectural meaning of the term πλινθεῖον, namely that of '(stone) door trim', as attested by papyrological (*PDura* 19.10 [88/89 CE]) and epigraphic (*Dura*⁷⁻⁸ no. 872 [157/158 CE], *YCIS* 14.1955.139.6 [169/170 CE]) documents (I take these references from Saliou 1992: 91 n. 95, quoted by Saliou 2004: 188 n. 12); see also LSJ s.v. III. 2 ('window-frame') and Hellmann (1992: 340 n. 1).

II.7 [10.19] **αὐτομάτου**. The correct reading (already conjectured by Schmidt) is transmitted only by manuscript **F**. All other manuscripts have erroneous readings. Two manuscripts (**Ea**, **Ta**) appear to correct αὐτομάτος to αὐτόματος, but the nominative singular masculine form likewise does not fit grammatically into the sentence. It is at any rate noteworthy that in Fabr. 93 the reading αὐτομάτου might have been influenced by the immediately following πλινθίου (in place of πλινθίον). The scribe would seem to have misread the ending of πλινθίον in his exemplar, which would presumably have led him to (mechanically) replace either αὐτομάτος or αὐτομάτως with αὐτομάτου.

II.8 [12.1-3] **τάσιν δὲ... πλινθίου**. We might suppose that the words τῆς λείας have fallen out between τὸ and βάρος (but cf. IX.4 [32.3] τὸ βάρος τῆς λείας). These words would complete the somewhat chiasmic structure of the passage, although τὸ βάρος can no doubt be understood without further specification (cf. V.5 [22.15], [22.16] and [22.20], XIII.8 [50.9], XIII.9 [50.10] and [50.12-13]).

II.8 [12.3-4] **αἱ δὲ ἐκτὸς τῆς πορείας κινήσεις**. All manuscripts read ἐκ in place of ἐκτὸς. This emendation has been tentatively proposed by Schmidt (app. crit. ad loc.) on the basis of XII.2 [42.11], which likewise refers to the movements other than locomotion of the case. Similar references are found at XVIII.3 [60.3-4] and XIX.1 [60.11] (supplemented), although in both these passages

ἐκτός is replaced by ἔξωθεν. But while these prepositions can be followed by the genitive to express an exceptive meaning ('apart from', 'except'; cf. LSJ s.vv. ἐκτός 3 and ἔξωθεν II.c), ἐκ is nowhere else attested in this sense (LSJ s.v. ἐκ I.5, however, record the earlier spatial meaning of 'outside of', 'beyond'). In a later discussion of the treatise, Schmidt (1903: 275) reconsidered his opinion and regarded ἐκ as equivalent to ἐκτός. The preposition is, by contrast, altogether omitted by Murphy 12 ('Movements in a forward direction').

II.8 [12.5-6] ἀποδεδεμένων... λείαν. Perhaps we should emend ἀποδεδεμένων to ἀποδεδομένων. Hero prefers the verb ἀποδίδωμι to refer to the attachment of cords (or chains: XIII.8 [50.9]) to the counterweight rather than ἀποδέω, which is used only here in the *Automata* (and only once elsewhere in the corpus in the same way: *Spir.* 94.9). There is further support for the proposed emendation in the fact that manuscripts oscillate between ἀποδεδεμένος and ἀποδεδομένος (XII.2 [42.18], XIII.5 [46.21]), and between ἀποδεδέσθω and ἀποδεδόσθω (V.5 [22.14], XII.3 [42.21], XIII.7 [48.17], XIII.8 [50.9], XVI.3 [54.21]; cf. *Spir.* 130.2, 180.3 and 180.5). But cf. II.7 [10.13] (προσδέω).

II.8 [12.6] ἔν τινι σύριγγι. On the shape and position of the σύριγγι, see note on V.5 [22.12-13].

II.8 [12.6-7] ἄρμοστῶς... εἰς αὐτήν. The adverbial pair ἄρμοστῶς/εὐλύτως is quite unique. Cf. also XI.2 [36.11] εὐλύτως καὶ ἄρμοστῶς. While ἄρμοστῶς is found nowhere else in Hero (and indeed only twice elsewhere: Papp. in *Ptol.* 91.4 and Hsch. η 767 Latte [paroxytone]), εὐλύτως appears 30 times, nearly one-half of the total occurrences of the adverb in Greek literature. In all but one instance (XIV.1 [50.20]), it occurs with verbs of motion, often describing the ease with which mechanical components (chiefly axles) are made to rotate: see, for instance, XI.2 [36.8] and [36.11] (cited above), XII.2 [42.19-20], XIII.7 [48.16], XVI.3 [56.1-2], XVIII.1 [58.12], *Bel.* 84.4-5, *Mech. Frag.* 1.1^{bis} = *Dioptr.* 308.4 and 310.24-5, *Spir.* 300.7 and 300.16. The combination of the two adverbs may be a stylistic alternative to a more expanded type of phrase such as that found at XVI.1 [54.13-15] περὶ δὲ τοῦτον [i.e. τὸν στυλοβάτην] περικεῖσθω ἵτις ἢ ἐξηθκλμν ἄρμοστὴ τῷ στυλοβάτῃ, ὥστε εὐλύτως περὶ αὐτὸν στρέφεσθαι (com-

pare this with *Spir.* 94.4-6; cf. also *Mech. Frag.* 1.1 = *Dioptr.* 312.4-5) or *Spir.* 204.5-6 (downward motion of a piston). This is implied, albeit indirectly, by Prou 163: '[l]e contrepoids... s'ajuste à la section du tuyau, de manière à pouvoir y descendre aisément'.

The term ἄρμωστῶς has been corrected in **A**. The scribe added two letters (in all likelihood οἱ) above the line. According to Schmidt (app. crit. ad loc.), these letters have been written above ὦς, but a closer look at the manuscript shows that they have been superscribed between ς (= στ) and ω (the accent appears above the final ς). One cannot therefore be sure whether the scribe intended to correct ἄρμωστῶς to ἄρμωστοὶ or to ἄρμωστοῖς. It is worth observing that in **A**, as in **T** (ἄρμωστοὶ ὦς, with οἱ above the line), the topmost point of ο is the starting point for a cross-stroke that goes straight through ι. This might be interpreted as the horizontal stroke of σ, were it not so long. It is difficult to resist the impression that both the scribe of **A** and the scribe of **T** copied the whole digram οἱ from a text they did not manage to decipher correctly.

II.9 [12.8-10] ἐν δὲ τῇ... ἐμβάλλεται. According to the explanation given by Landels (1978: 204), dry sand is preferred in stationary automata because it flows out more slowly, and thus allows for a longer performance. It would have been superfluous for Hero to spell this out, since emphasis is already placed on the properties of millet and mustard (διὰ τὸ κοῦφά τε ἀμφοτέρωθεν εἶναι καὶ ὀλισθηρά) as opposed to sand. Unlike other translators, who render ὀλισθηρά literally ('glissants', Prou 163; 'schlüpfrig', Schmidt 347; 'slippery', Murphy 12), Baldi 18^r ('flussibile') and Couture 245 ('fluxa') have the correct understanding of the term (so also Cambiano 2011: 31 n. 13); cf. the use of the term to refer to foods that pass easily through the digestive system, as, for instance, in Gal. *Al. Fac.* 6.536, 562, 587, 593, 634 Kühn. The contradiction between the present description and that of IX.4 [32.5-6] (κοῦφόν τι καὶ λεπτόν καὶ γλίσχρον, οἶον κέγχρον ἢ νᾶπυ) is only apparent, since there is a difference in emphasis (in the latter case stress is laid on the necessity to prevent abrupt motion of the case, as is made explicit in the immediate context: IX.4 [32.2-4]; cf. IX.6 [32.14-15]). There seems to be a preference for millet over mustard because the former is mentioned far more frequently than the latter (in addition to the passage quoted, cf. IX.5 [32.12], IX.6 [32.16], XVII.2 [56.18] and XIX.2 [60.20]).

II.9 [12.10-13] ὧν ἐκρεόντων... σπάρτον. These lines are complemented by IX.5-6 [32.7-17], even though the focus there is limited to the motion of the case. Schmidt 349 is surely right, therefore, when he keeps the plural τὰς κινήσεις ('die Bewegungen'). Other translators, on the other hand, are not so scrupulous, since they all render the term as if it was singular (but perhaps we must concede that a certain degree of generalisation is involved).

The adverb ἡρέμα is used by Hero on three other occasions, once with reference to the downward flowing of millet (IX.5 [32.13]), and twice to connote the gradual vertical movement of water – either upward (*Spir.* 238.2) or downward (*Spir.* 248.14); contrast the use of πράως/πραέως for the gentle stretching of a cord (II.11 [14.6], XXIII.8 [78.18]).

For a modern application of the principle described here (i.e. decentring of arches by the so-called 'sand box' method), see Prou 163-5; see also, most recently, Varghese (2007: 79-80 with Fig. 8.4).

II.9 [12.12] τὰς κινήσεις ἀποτελεῖ. Perhaps we should emend ἀποτελεῖ to ἐπιτελεῖ. The verb ἀποτελέω is generally used by Hero to refer to the production of sound (ἤχον: e.g. XIV.2 [52.3] and [52.5], XX.4 [66.18], *Spir.* 98.2 and 100.14; φωνή: *Spir.* 316.16 [of a blackbird] and 320.13), whereas ἐπιτελέω is the usual verb for carrying out movements (cf. note on I.1 [2.7-8]). For the scribal confusion between ἐπιτελέω and ἀποτελέω, cf. app. crit. to XIX.4 [62.10].

II.9 [12.13-14] ἀρχὴ δὲ... σπάρτου. I follow Schmidt in adopting the reading τάσις, which appears in the *ed. princ.* This reading seems to be a correction because the manuscripts used by Thévenot have either the erroneous πάσις (**Pa** and **Pf**, like **AGT**) or σπάσις (**Pd**, like **M**). τάσις is preferable to σπάσις (possibly a conjecture based on the preceding ἐπισπωμένη) not only because Hero uses the term elsewhere to refer to the stretching of a cord (XI.4 [36.25], XXX.2 [106.16], *Bel.* 83.6) but also because it forms an antonymic pair with ἀπόλυσις (note parallelism: τάσις σπάρτου... ἀπόλυσις σπάρτου).

The vast majority of manuscripts read the second colon as follows: κινήσεως δὲ στάσις ἀπόλυσις σπάρτου. (Manuscripts Par. gr. 2519 and Leid. Bon. Vulc. 4 replace στάσις, respectively, with στάσεις and τάσις, but these readings can be dismissed as mere errors.) The perplexing phrase κινήσεως δὲ στάσις has so far

been understood as referring to the end of motion. In particular, Baldi 18^r, followed by Couture 245-6, interpreted the term στάσις as denoting both the endpoint of motion and the subsequent state of rest: ‘fine e stato del medesimo [i.e. il moto]’ (Baldi’s words ‘stato del medesimo’ are not without ambiguity, as they might also be taken to mean ‘state of motion’). However, there are two arguments against this interpretation. First, στάσις is nowhere attested with the meaning ‘end’ (for a review of the different meanings of the term, see Artés Hernández 2014: 183). Second, it is extremely difficult, if not impossible, to explain why rest should be predicated of its opposite (cf. LSJ s.v. στάσις II.B.1 and, especially, Pl. *Sph.* 252d6-11, 255a4-b2). Even admitting that motion indeed partakes of rest (Pl. *Sph.* 256b6-9; for a detailed discussion of the different interpretations proposed for this problematic passage, including his own, see Movia 1991: 370-3; with a different perspective, see, more recently, Ambuel 2007: 153-4), the term κίνησις, as used by Hero, should not be taken in the Platonic sense as referring to the pure form of motion (as Movia 1991: 372 with n. 128, following Rosen 1983: 279, believes is the case with Pl. *Sph.* 256b6 αὐτὴ κίνησις). On these grounds, therefore, I have taken στάσις as an intrusive gloss and emended to τέλος. It is plausible to presume that a scribe glossed the original phrase κινήσεως δὲ τέλος with the term στάσις (cf. the definition of Max. Conf. *Amb.* 15.7 = *PG* 91.1217C τῆς δὲ τῶν γεγενημένων φυσικῆς κινήσεως τέλος ἢ στάσις ἐστίν, cf. also Alex. *Aphr. in Top.* 361.19-20), and that this gloss was later mistaken for a variant reading. This explanation has the additional advantage of allowing us to restore parallelism to the lexically and conceptually unrelated elements of the chiasmus (ἀρχή/στάσις) through substitution of στάσις with τέλος (ἀρχὴ δὲ κινήσεως... κινήσεως δὲ τέλος).

II.9 [12.14-15] ἐκπεσούσης... ὀργάνῳ. We need to understand τῆς ἀγκύλης as referring to the loop of cord, as is clear enough from the preceding context; cf. also the use of the verb προσαγκυλόομαι at II.7 [10.13] (conjecture), II.8 [12.4] and II.11 [14.8]. The definition of II.7 [10.14-15] (τὸ δὲ κινούμενον ἄξων ἐστίν, etc.) does not justify Couture’s inference that the words τῷ κινουμένῳ ὀργάνῳ must exclusively mean an axle (‘axi’, 246; cf. Prou 162). In addition to being found on axles (wheel axle: cf. esp. V.4 [22.4-5], and XII.3 [44.1-2] τῆς ἀγκύλης ἐκπεσούσης ἀπὸ τοῦ τύλου, with note ad loc.; door axle: cf. esp. XXIII.6

[78.3-4]; cf. also XXVIII.7 [104.10], and Orib. 49.4.25 for a definitional approach), a τύλος ('knob') is also found on such devices as pulleys (XXIV.6 [84.8-9], XXVII.4 [98.20-100.1]; for the use of multiple knobs in a different context, cf. XXIX.1 [104.19-20]). Whenever a loop of cord falls off its knob, motion is interrupted, even if imperceptibly (change of direction: VI.2 [24.7-9]; cf. VI.2 [24.11]), or brought to an end (V.5 [22.19-20], given as an alternative to the complete descent of the counterweight, and XXIV.6 [84.9-10] [corrupted]; cf. also the parallel expression quoted above). In order for the loop of cord to fall off, it must not be fixed in any way; cf. *Bel.* 83.1-2 ἀγκύλας...περόναις ἀπολαβόντες ταῖς ΞΟ, ΠΡ, ὥστε μὴ ἐκπίπτειν τὴν νευράν.

For the use of the term τύλος in a different sense, 'wooden block' engaging the thread of a screw, cf. X.2 [34.8], [34.11] and X.3 [34.13]; on this usage, cf. esp. *Mech. Frag.* 2.5 ^{quinquies} = Papp. 1126.3, 1126.9, 1126.10, 1126.15, 1126.17 (Ferriello-Gatto-Gatto 2016: 37 curiously translate the word as 'hinge'; but see Ferriello-Gatto-Gatto 2016: 376); the term has been borrowed into Arb. *tūlus* (cf. *Mech.* 2.5 and 2.19, with Drachmann 1963a: 59, 81; see also Laird 2015: 300).

II.10 [12.17] οὐκ...ποιοῦνται. I prefer the reading ποιοῦνται (**A^{pc}GT¹**) to ἐμποιοῦνται (**A^{ac}MT²**) not only because it receives better manuscript support but also because the verb ἐμποιέω is never used in Hero. **M**'s supralinear ἀνισοταχεῖς is clearly a correction of the corrupt ἀκισοταχεῖς.

II.10 [12.18-19] διὰ τὸ μὴ...ἐλάσσονας. Murphy 40 n. 6 explains Hero's reference to instruments of different diameter by saying that 'the different sizes of the axles – like differential gears – allow events in the moving automaton display to occur in sequence'. This misses the point entirely. First, Hero uses the term ὄργανον to refer to any kind of circular component, as the reference to bigger and smaller circles at XVIII.3 [60.2] makes clear. Second, cogwheels are nowhere used in the treatise (Introduction, p. lxxviii). Third, the possibility of a series of movements depends on the use of slackenings (II.10 [12.19-14.3]) rather than on the different size of the axles. Rather, Hero's point is that since instruments of different diameter rotate at different speeds, they impart different velocities to the components connected to them. The greater the diameter, the

longer the time required to complete a single rotation, and therefore the slower the movement.

Here the adjective ὅμοιος denotes geometrical equality rather than geometrical similarity, because, mathematically speaking, all circles are similar (Hero, *Deff.* 118; Giardina 2003: 344). For this meaning LSJ s.v. III.1 cite only three passages from Aristotle (*Cael.* 296b20, 297b19, 311b34) and Thales *ap. Procl. in Euc.* 251, all with reference to angles. This use of the term seems to reflect a naïve usage rather than an archaic (ἀρχαϊκώτερον, Procl. *in Euc.* 251.1) usage (Rankin 1960: 75-6).

II.10 [12.19-14.2] **δεῖ δὲ τῶν... τετάσθαι.** Manuscript **Ph** reads ἀνατετάσθαι in place of ἅμα τετάσθαι. This reading does not suit the context, for all the cords that are attached to the counterweight extend upwards (XVII.2 [56.18-20]). It is not clear whether Baldi's exemplar read ἀνατετάσθαι, ἀνατετᾶσθαι (as in **M**) or simply τετάσθαι ('Bisogna anco, che le corde... non siano tese'). Couture 246 ('Observa... funes tensos esse omni ex parte') is more emphatic.

II.10 [14.2-3] **ἀλλὰ... ἔχειν.** This is so because, when a cord is slack, it does not transmit force to the instrument to which it is connected. Hence, if a cord has some slack to it, it must be made longer (Prou 173). As Baldi 43^v rightly pointed out, the arrangement of the so-called χαλάσματα into hanks (μηρύματα, cf. II.11 [14.4-6] with note ad loc.; cf. the use of the verb διαμηρύω at X.3 [34.16], XI.11 [42.6], XVI.3 [56.7]) glued onto their respective instruments prevents cords from tangling (see also Drachmann 1963a: 197). These slackenings are used either to delay the start of movements (locomotion of the case: IX.6 [32.14-15], XI.6 [38.11-14], XIX.3 [62.4-9]; all other movements: XIX.4 [62.12-14]) or to produce pauses between motions (forward and backward motion: VI.2 [24.12-15], VI.3 [24.19-20]; rectangular motion: IX.4 [32.1-2], X.3 [34.14-17]; snake-like motion: XI.4 [36.21-4], XI.5 [38.1-3] and [38.4-6], XI.7 [38.19-22]; dances of the Bacchantes: XVI.3 [56.6-8]).

II.11 [14.4-6] **τὰ δὲ χαλάσματα... τόπον.** For the function of such an arrangement, cf. previous note.

Μήρυμα is the term normally employed by Hero to refer to the slack coils of cord (hanks): VI.3 [24.20], XI.5 [38.4], XI.6 [38.7]; cf. VI.2 [24.12] (μηρυμάτιον). We also find it in his *Belopoeica* (81.11, 82.3), where it denotes a hank of spring-cord (Marsden 1971: 23); cf. Ph. *Bel.* 65.22, 66.1, 67.23-24 (note that these occurrences have been rendered differently by Marsden 1971: 133, 135; cf. also LSJ s.v. μήρυμα). The present occurrence has been translated by LSJ s.v. as ‘kink’ (a translation largely adopted by Murphy; contrast her strange renderings of VI.2 [24.12], ‘stretches’ [15], and of VI.3 [24.20], ‘lengths’ [17]), but this understanding does not accord well with the gloss given by Hsch. μ 1259 Latte μήρυμα· σπείραμα. ἢ ἐκτεινόμενον (μήρυμα is the reading of the Cyrillian manuscripts, against μήρυγμα, which is transmitted by the Hesychian manuscript: see Latte’s app. crit. ad loc.; for μήρυγμα, cf. also Nic. *Th.* 160, 265). At XI.4 [36.24] all manuscripts read χάλασμα τοῦ μηρίσματος (μερήσματος T^{ac}). Likewise, μήρισμα receives a gloss, albeit interpolated, in Hsch. μ 1263 Latte (μήρισμα· κάταγμα, ἢ σπάσμα ἐρίου), although the non-Hesychian branches of the tradition have in its stead μήρυγμα (Cyrillian manuscripts) or μήρυμα (Συναγωγή λέξεων χρησίμων, on which see Cunningham 2003); see Latte’s app. crit. ad loc. Now, we must remember that Salmasius thought fit to emend μήρισμα (almost certainly an error owing to iotacism) to μήρυσμα (see app. crit. to Hsch. μ 1262 Schmidt) and, more importantly, that Schmidt 374, treading in Salmasius’ steps, printed μηρύσματος (which I have accepted in my text) in lieu of μηρίσματος (a conjecture anticipated by L. Dindorf *ap. TGL* s.v. μήρυμα, yet with doubts expressed about the soundness of the reading because of the σ). While they correctly pointed out that both of these instances of μήρυσμα (treated as equivalent to μήρυμα in LSJ s.v. μήρυσμα) are in fact conjectures, LSJ s.v. μήρισμα failed to notice that there is some manuscript evidence, however slim, for this form. So, **G** transmits μηρύσματα instead of μηρύματα (**AT**) in the present passage, and the *ed. princ.* has μήρυσμα in place of the correct σμήρισμα at *Spir.* 252.4. Therefore, notwithstanding Dindorf’s doubts and Lobeck’s (1837: 433) complete rejection of the term, μήρυσμα may well have been regarded, along with μήρυγμα, as an acceptable variant of μήρυμα (a view implicitly embraced by Schneider 1801: 120; Lobeck 1837: 433 n. 1 suspected the term μήρυγμα, too, but did not propose any emendation, as erroneously maintained by Schmidt in his app. crit. to Hsch. μ 1258 μήρυ[γ]μα).

For this reason, and in the absence of conclusive grounds for rejecting μήρυσμα, I have treated **G**'s μηρύσματα as a mere variant reading, relegating it to the app. crit., and accepted Schmidt's conjecture at XI.4 [36.24].

It remains to consider, however briefly, the reading that we find in **M** (μὴ ῥύματα). This seems best explained as due to wrong word-division. Not only is the negative utterly misplaced, but the word ῥύματα, no matter how we interpret it, does not convey a reasonable sense. Even if we leave aside ῥύμα ('stream'), we are left with two omographs, namely ῥῶμα/ῥῶμα: the first ('bow-shot', 'towline') comes from ἔρύω ('drag', 'draw'), the second ('defence', 'protection') from ἐρύομαι ('protect', corresponding to LSJ s.v. ἐρύω (D)), and not from the middle of the said ἔρύω, as with LSJ s.v. ῥῶμα (B). Cf. Chantraine, *DELG* s.vv. ἔρυμαι and ἔρύω.

II.11 [14.7-10] *προσέχειν δὲ δεῖ... λήψεται*. Hero's apparently pedantic insistence on the proper arrangement of cords culminates in a premonition of the automaton's potential failure; cf. II.4 [8.11-12]. Especially noteworthy is the repetition of the expression ἐπ' ἀριστερά. Scholars such as Baldi 18^v and Prou 173 interpreted these words as denoting direction. While the latter took them literally ('à gauche', cf. Hero, *Deff.* 8), the former understood them somewhat more loosely ('al contrario'). The unspoken implication of both these renderings is that the cords should only be wound rightward in order to guarantee smooth functioning of the device, but Hero never gives so many details in connection with the winding or the fastening of cords. So, for example, when a cord must be wound in the opposite direction – τὰ ἐναντία (VI.1 [24.1-2], VI.2 [24.14]; cf. VI.2 [24.12]), not ἐπ' ἀριστερά – the direction of winding is not specified. Couture 246, in turn, went too far astray with his paraphrase ('ne circumvectiatur alieno [sc. instrumento]'), which covers the words μὴ... λάβῃ), failing even to notice that the phrase was repeated a second time in the original text. Taking a different perspective, Schmidt 349 ('verkhert') and Murphy 13 ('incorrectly'), with whom I agree, understood the phrase ἐπ' ἀριστερά in a metaphorically extended sense, thus shifting the focus from the direction of winding to the manner of winding. The interesting point here is that the adjective ἀριστερός is used as an antiphrastic euphemism (see generally Caroli 1999: 52-3 with n. 24, with bibliography) to avert ill luck and ward off a potential breakdown of the auto-

maton (contrast its use at III.3 [16.14], where it simply denotes the left hand of the figure of Dionysus, without bearing any mantic or religious overtones; cf. the passage quoted above from Hero's *Definitions*, and XXVI.5 [94.8] ἐν τοῖς εὐωνύμοις μέρεσιν); *contra*, Chantraine (1955: 376-7; 1956: 64-5), according to whom the euphemistic sense of ἀριστερός faded away after the fifth or fourth century BCE (but see, for instance, Plu. *De Iside et Osiride* 378b, *Didache* 12.1, cited in *DGE* s.v. 2; cf. also *LSJ* s.v. 4). Further, this apotropaic function is intensified through repetition. One could even go so far as to say that Hero invests mechanics with the supernatural power of prediction and omen reading, because he is employing a term whose origins lie in bird augury and divination (see Caroli 1999: 52). On mechanical foreseeing, cf. also the use of the verb προμηχανάομαι at XXVI.6 [94.17].

II.12 [14.11-12] δεῖ δὲ καὶ... φαίνεται. On the significance of this claim, see my remarks in the Introduction, p. cix. Drachmann (1948: 100) argues rather cryptically that the claim applies not only to the scenic presentation of the automaton ('the plays of the theatre') but more generally to Hero's (technical) ability to innovate, particularly in the *Pneumatica*. He bases his argument on the fact that only a few of the instruments described in the work are connected with Philo's homonymous treatise (see Introduction, p. cvii). Even if we leave aside the questionable basis of his argument, I still do not understand why the claim should be extended to cover the *Pneumatica* or, indeed, the whole of his work. Hero makes it quite clear that he is referring to the appearance (φαίνεται) of the automaton.

Couture 246 and Murphy 13 take κατασκεύασμα to refer to the scenic presentation *tout court*. Baldi 18^v ('opera') and Schmidt 349 ('Apparat'), by contrast, translate correctly. The term κατασκεύασμα is used only once elsewhere in Hero: *Spir.* 238.1 (automatic fountain; Drachmann 1948: 154-6).

II.12 [14.12-14] δυνατόν... ποιῆσθαι. This clearly refers back to I.8 [6.4-7]. On the significance and implications of this statement, see note on I.7 [4.20-2].

II.12 [14.14-15] βέλτιον δ' ἐν τούτοις ἀναστρέφεται. I adopt Schmidt's tentatively suggested ἀναστρέφεται (anticipated by Baldi 18^v, with 'si porterà') in

place of ἀναστρέψει (note that Schmidt's translation presupposes the middle form of the verb: 'grösser wird sein Erfolg sein', 349). According to LSJ s.v. A, the verb ἀναστρέφω, in the active voice, primarily means 'turn upside down', 'turn back', 'write with anastrophe' and secondarily 'invert', 'retire', 'deny/refuse' (occurring only once in this sense, as equivalent to ἀρνέομαι, in S. *Fr.* 1012) 'rally' and 'convert', but none of these meanings fits within the context. In the passive voice, by contrast, the verb has, among other meanings, that of 'conduct oneself', 'behave'. Thus used, it is sometimes construed with ἐν + dative, and can be qualified by an adverb (for examples of this usage, see LSJ s.v. B.II.1). In support of his conjecture, Schmidt (app. crit. ad loc.) cites *Spir.* 2.11 (ἐν τοῖς μαθήμασιν ἀναστρέφεσθαι), *XX.1* [64.3-4] (ἀνεστράφθαι ἐν τοῖς προγεγραμμένοις) and *Ph. Bel.* 59.28-9 (ἐν πᾶσιν [sc. ὀργάνοις] ἀναστραφῶ). Of these passages, the first two are not close enough to provide support. First, the verb ἀναστρέφομαι is used, respectively, in the senses of 'to be engaged in' and 'dwell upon' (both meanings are recorded by LSJ s.v. B.II.1). Second, the preposition ἐν, as used in the second passage, has a more concrete sense than it is used here (ἐν τούτοις, sc. 'automata-making'). On the other hand, the Philonic passage provides a more appropriate comparison, since the passive of ἀναστρέφω is accompanied by the adverbial expression ὃν ἐγὼ βούλομαι τρόπον. Here the corruption probably arose from the confusion of the tachygraphic sign for -ται (for which, see Allen 1889: 24 with Pl. VII; Gardthausen 1913: 340) with ῖ.

III-IV [14.17-20.7] Arrangement and performance of the mobile automaton

After giving the dimensions of some of the most important parts of the automaton (III.1), Hero describes its arrangement (III.2-4) and its performance (IV.1-3). The performance consists of three distinct phases: forward motion, apotheosis of Dionysus, and backward motion (Prou 138, 165-6). The main scene involves two almost identical series of movements. There are six different movements, each of which is controlled by a separate cord (Olivieri, 1901: 426; Schmidt 1903: 276). The movements occur one after the other in the following order: (1) lighting of either of the altars (cf. XII); (2) sacrificial libation of wine and milk or water (cf. XIII.1-7); (3) sinking of garlands (cf. XV; occurring only once); (4) dance of the Bacchantes (cf. XVI) and (5) sound of kettledrums and

cymbals (cf. XIV); (6) half rotation of Dionysus and Nike (cf. XIII.7-9). Despite lack of explicit mention, the last of these movements will have been performed twice, too (cf. XIII.8 ὅπως ἅμα ἀποκατασταθῶσιν ἢ τε Νίκη καὶ ὁ Διόνυσος). With a renewed attention to the dimensions of the automata, particularly of the mobile type, Hero closes the section (IV.4) by emphasising the apparent absence of human intervention.

III.1 [14.17-18] <Ἔστω>... τριῶν. Schmidt's supplement is necessary because the sentence lacks a main verb. The omission of Ἔστω may have been accidental, owing to its similarity to the preceding ἔστι. For ἔστω βάσις at the beginning of a sentence, cf. *Spir.* 80.6, 88.3, 224.2, 242.12; cf. also XIII.3 [46.1].

The dimensions given here are only approximate (for the use of ὥς to denote approximation, cf. LSJ s.v. E; cf. also III.1 [14.21] and [16.4]), as was already recognised by Baldi 19^v and Schmidt 353. Couture 246 translated the first ὥς ('circiter'), but omitted the last two. Less felicitously, the presence of the adverb (here, as at III.1 [14.21] and [16.4]) has been overlooked altogether by Murphy 13 and McCourt (2012: 196). Based on Hultsch's (1882: 697) table of correspondences, Schmidt 353 with n. 2 gave the approximate metric equivalents of Hero's measures (length: 46 cm; width: 31 cm; height: 23 cm). This is remarkable not only for the different degrees of approximation used, but also because the height of the κίονια (for Schmidt's misunderstanding of the term, see note on III.1 [16.3-4]), which is given in the text as approximate (62 cm), is elsewhere (Schmidt 353 n. 3) specified as being 61.7 cm. For the sake of consistency and clarity, I prefer to give exact figures rather than approximations (see already Prou 140 n. 55), since the degree of approximation is unknown (I, too, base myself on Hultsch 1882: 697). The base is about 46.24 cm long (one cubit), 30.83 cm wide (four palms) and 23.12 cm high (three palms), which means that we must imagine a very small casing. It thus becomes clearer why the automaton needs to be constructed out of lightweight materials (II.2 [6.17-8.2]). For the dimensions of the column shafts (κίονια), cf. note on III.1 [14.20-16.1]; the measures of the whole column and of the architrave are discussed in note on III.1 [16.3-4].

III.1 [14.18-19] κυμάτιον ἔχουσα περιτρέχον. The term κυμάτιον is strictly architectural, and denotes any vertical convex moulding (for an analysis of the term, see Hellmann 1992: 245-7). Previous translations are not accurate, since the term has been interpreted as meaning either ‘cornice’ (Baldi 19^v), ‘curved line’ (‘coronide’, Couture 246), or ‘groove’ (Murphy 13; McCourt 2012: 196). Schmidt 353 has ‘Hohlkehle’. That would be a ‘hollow [sc. concave?] moulding’, whereas κυμάτιον can, at best, refer to the cyma reversa, which is a compound moulding (both convex and concave); see Hellmann (1992: 246).

For the phrasing, cf. Ph. *Bel.* 66.27 κυμάτιον πύξινον... κύκλω περιτρέχον and 67.1 πύξινον περιτρέχον κυμάτιον. In these instances, the term points to the moulding that runs on the protective cover of Philo’s wedge-catapult (cf. also Ph. *Bel.* 62.7-8). It is, in my opinion, overinterpretation to regard Philo’s κυμάτιον as a ‘wave-moulding’ (Marsden 1971: 127 for Ph. *Bel.* 62.8) or a ‘beading’ (Marsden 1971: 135 for Ph. *Bel.* 66.27 and 67.1). On Philo’s wedge-catapult, see Marsden (1969: 42).

III.1 [14.20-16.1] κίονια... δύο. The column shafts have a height of approximately 61.68 cm (eight palms) and a diameter of 15.41 cm (two palms); compare the figures given by Schmidt 353 with n. 3: 62 cm (or 61.7 cm) and 15.5 cm, respectively; see also note on III.1 [14.17-18]. Manuscript **Tb** reads εἴκοσι (154.2 cm) instead of ἡ, a dimension which would result in a disproportionate height for the columns. This erroneous reading must have arisen from the confusion between minuscule η and κ (κ corresponds to twenty), as confirmed by the fact that the scribe later corrected the mistake by adding ἡ in the margin. For the suggestion that the κίονια should measure ten palms (77.1 cm) in height, see McCourt (2012: 196); for discussion, cf. note on III.1 [16.3-4].

III.1 [16.2-3] ἐπὶ δὲ τῶν... κύκλω. There seems to have been some confusion about the meaning of the term ἐπιστύλιον. Baldi 43^v n. 16 was the first to comment on Hero’s usage of the term. According to the Renaissance scholar, the measures of the ἐπιστύλιον (which, as he acknowledged, properly signifies ‘architrave’) given in the following line, III.1 [16.3-4] (for discussion of these, see following note), mean that there is no room for both the frieze and the cornice, and so Hero would be using the term to denote any ornament that is laid upon

the columns. He, therefore, explained his translation ('cornice', Baldi 19^v) by saying that it would have been inconvenient to leave out (what he thought to be) the main element of the entablature rather than the architrave and the frieze (but the opposite is, in fact, the case, with the architrave being the main element, and frieze and cornice the accessory elements: see, for instance, Ginouvès 1992: 110 with n. 440). These observations are especially interesting because they suggest that what is really needed on top of the columns is not an architrave (or something like it; on Schmidt's addition, see below) but a whole entablature. If we leave aside Couture's translation ('coronis', 246; also used for the *κυμάτιον*: see note on III.1 [14.18-19]), we are left with three major interpretative possibilities: (1) *ἐπιστύλιον* means 'architrave' (Schmidt 353; Murphy 13); (2) *ἐπιστύλιον* means 'entablature' or 'crown(ing)' (Prou 229 n. t); (3) *ἐπιστύλιον* means 'lintel' (McCourt 2012: 196). We can dismiss the third possibility right away, since the lintel is commonly found across the top of a door or window, and no such element occurs here. The second possibility is more problematic. First, entablature and crown(ing) do not coincide. The word used by Prou for the latter, 'couronnement', can, at best, refer to the upper element of the architrave in the Doric and Ionic orders (Ginouvès 1992: 111-14), but certainly not to the entablature ('entablement'). Second, the term *ἐπιστύλιον* can be used to denote both the architrave and the entablature (Ginouvès 1992: 110-11). If we follow Gros (2010: 131) in maintaining that the term has gradually extended its meaning to include the frieze and the cornice since the beginning of the Imperial period, we would be led to think that *ἐπιστύλιον* here means 'entablature'. However, the fact that in the immediately following context the dimensions of the *ἐπιστύλιον* are defined in terms proportional to the height of the whole column suggests otherwise, as this is how, according to Vitruvius (*De Arch.* 3.5.9), the proportion of the Ionic architraves should be calculated (see Chitham 2005: 22). I have, therefore, translated *ἐπιστύλιον* as 'architrave', in the belief that it still retains its original meaning. All things considered, the first possibility is the likeliest one, and the one that adds to the understanding of Hero's automaton in relation to ancient architectural practice. What Hero has in mind is, perhaps, the Ionic order.

Now that the meaning of the term is clear, it remains to consider the shape of the architrave. Schmidt 351 Fig. 82 seems to invite us to imagine, and rightly so,

a rectangular (so also Baldi 19^r unnumbered Fig.) architrave, since its general shape is made to match that of the case. By contrast, Murphy 13 and 41 n. 9 defines the ἐπιστύλιον, in a rather idiosyncratic way (but see also McCourt 2012: 196), as being circular (as opposed to oval [?]), although this cannot be easily inferred from her graphic representation of the automaton (Murphy 14 Fig. 1). Such a view depends on an erroneous interpretation of the word κύκλω (cf. also III.2 [16.6], XXVI.7 [96.2]), which is used adverbially with the sense of ‘in a circle’, ‘(all) around’ (LSJ s.v. κύκλος 2) and cannot refer to the shape of the architrave. Had Hero meant to assign a circular shape to this element, he would have probably said στρογγύλον ἐπιστύλιον (for the adjective στρογγύλος used in this way, cf. III.2 [16.8], XVI.1 [54.10] and [54.11]; cf. also XXVI.2 [92.1]). It may be worth wondering in this context whether the original text would have read κύκλω <περιτρέχον>, which seems implied by Baldi’s ‘che corre intorno’ (19^v) and Couture’s ‘circumducta’ (246). Cf. III.1 [14.18-19] κυμάτιον... περιτρέχον, with note ad loc. (especially compare Ph. *Bel.* 66.27, cited there).

Schmidt’s proposed <τι> is needed because the phrase καθάπερ ἐπιστύλιον cannot serve as the grammatical subject. In his app. crit. Schmidt adduced a parallel passage from Ph. *Bel.* 62.4 ἐπικεῖσθαι τι καθάπερ ἐπιστύλιον, said of the protective cover of the frame of Philo’s wedge-catapult; see Marsden (1969: 61), and note on III.1 [14.18-19]. For a similar expression, cf. Gal. *San. Tu.* 6.344 Κύην (ἐγκεῖσθαι τι καθάπερ λίθον).

III.1 [16.3-4] ὕψος... ε̄. Previous scholars have been misled by these measures. According to Schmidt’s interpretation (353 with n. 4), one-eighth of the height of the whole column corresponds to 7.71 cm, that is, one palm (one-eighth of the height of the κίονια in his understanding: III.1 [14.20-1]), and this does not match the figure given by Hero, five fingers (9.65 cm). He therefore suggested with some hesitation that ε̄ should be emended to δ’ (but how would the corruption have occurred?) because four fingers correspond to one palm (see Hultsch 1882: 697). Although not brave enough to adopt his conjecture in the Greek text, in his translation he opted for ‘vier’ rather than ‘fünf’. Schmidt’s conjecture was later endorsed by Murphy 40 n. 9, who, despite everything, preferred to follow the manuscript reading and, hence, to translate ‘five’ (Murphy 13). This, however, is contradicted by the height assigned to the architrave in Murphy 14 Fig. 1

(one palm). A slightly different stance has more recently been taken by McCourt (2012: 196), who thought that the height of the κίονια, 'eight' ($\overline{\eta}$) palms, should be changed to 'ten' palms (77.1 cm), that is to say, in Greek numerical terms, ι. This would solve the hypothetical discrepancy between the two different measures of the architrave (one proportional, the other numerical), given that one-eighth of ten palms equals five fingers. This escamotage has the advantage of leaving $\overline{\epsilon}$ unaltered, provided that we are ready to accept $\overline{\eta}$ as an error of some sort. I believe that it is possible to account for these measures without having to assume that the text is corrupt. As has become clear, all the scholars mentioned above treat the phrase τοῦ κίονος ὅλου in the same manner as they treat the κίονια of III.1 [14.20], but Hero's usage of the adjective ὅλος seems to imply a contrast. So, if Murphy 13 translates κίονια as 'little columns' (see already Baldi 19^v; Couture 246), Schmidt 353 and McCourt (2012: 196) rather think of them, respectively, as 'pilasters' ('Pilaster') or 'small pillars'. What has so far gone unnoticed, though, is that at III.1 [14.20-16.2] the κίονια are mentioned alongside base-mouldings (σπειρία) and capitals (κεφαλαί), which strongly suggests a different meaning for the term κίονιον, that of '(column) shaft' rather than of 'column'; for a comparable usage of the primitive form κίων, see Hellmann (1992: 217). Thus, when Hero says that the architrave is one-eighth the height of the whole column, he most probably means the column with all its formal elements, namely base, shaft and capital (see, for instance, Ginouvès 1992: 62). We find that there is no discrepancy between the two measures of the architrave, because in the previous lines Hero has not given the dimensions of the whole column, but only those of the column shaft (for these, see note on III.1 [14.20-16.1]). The architrave, therefore, measures approximately 9.65 cm (five fingers) in height, a measure which equates to one-eighth of the height of the whole column. We can easily deduce the height of the whole column, 77.2 cm, a figure which comprises shaft (approximately 61.68 cm), base and capital (these two, taken together, being approximately 15.52 cm).

As for the width of the architrave, Murphy 40-1 n. 9 has drawn attention to the fact that it is not specified in the text, arguing that it has to be at least six palms to match the long side of the case (see also Murphy 14 Fig. 1); but what she has in mind is a circular architrave (cf. previous note). There is no reason to suppose that the long and short sides of the (rectangular) architrave are much

different from those of the case, approximately 46.24 cm and 30.83 cm, respectively.

III.2 [16.5] κατὰ δὲ... σανίδια. The plural τῶν ἐπιστυλίων transmitted by all manuscripts cannot be right because it contradicts the previous mention of only one architrave (III.1 [16.3]). R. Schöne conjectured τὸ ἐπιστύλιον, which would, in effect, agree with Hero's natural preference for κατὰ + accusative. However, Schmidt's doubtful suggestion (τοῦ ἐπιστυλίου) fits better into the context. The verb καταστόρνυμι (or καταστορέννυμι or καταστρώννυμι) and its uncompounded form are most generally used in conjunction with κατὰ + genitive rather than with κατὰ + accusative: cf. the expressions κατὰ τοῦ ἐδάφους κατεστρωμένος (Dsc. 2.130.1) and κατὰ γῆς ἐστρωμένος (Dsc. 3.126.1, 4.15.1; cf. Him. *Or.* 12.116). The corruption probably arose from the occurrence of the plural δακτύλων in the immediate vicinity (III.1 [16.4]). For κατὰ τοῦ ἐδάφους, cf. V.5 [22.18-19].

III.2 [16.7-8] ναῖσκος στρογγύλος περιφανής. The manuscripts **Pc** and **Pg** both offer the marginal variant reading περιφερής for περιφανής. The adjective περιφερής has several meanings, only one of which would be pertinent here ('rounded' or 'curved', LSJ s.v. I.2). LSJ s.v. I.2.a-c give two instances of the use of περιφερής in combination with στρογγύλος (Hp. *VC* 11 and, in a metaphorical sense, D.H. *Rh.* 10.13; for this combination, cf. also Pl. *Ep.* III 342b8, [Arist.] *Mech.* 851b15, Corn. *ND* 56.9 Lang, Plu. *Cur.* 517e, Gal. *UP* 3.216 and 658 Kühn, Hsch. δ 1855 Latte), and one instance of the use of the term to mean 'domed' (περιφερεῖς στέγαι, Demetr. *Eloc.* 13). This reading is therefore either an intrusive gloss that has replaced περιφανής or a deliberate conjecture, for it is unlikely that Hero would have laid more emphasis on the shape of the shrine. What matters here is the conspicuous appearance (περιφανής) of the shrine ('ri-guardevole', Baldi 19^v; 'von allen Seiten sichtbar', Schmidt; cf. also Prou 140 and 142), situated as it is in the middle of the κατάστρομα.

Couture 246 ('aedicula... ad aspectum jucunda') overemphasises the aesthetic element here, but only at the cost of obscuring the sense. Murphy 13, on the other hand, translates 'free-standing', which erroneously implies that the shrine is not attached to the underlying surface. This interpretation seems to de-

pend on the translation given to περιφανής by LSJ s.v. 1, who understand the expression περιφανή... ζῶα (Callix. *ap. Ath.* 199e = *FGrH* 627 F 2, further compared to Callix. *ap. Ath.* 205c = *FGrH* 627 F 1) as indicating 'figures standing and unattached', in contrast to figures in relief (πρόστυπα). But in fact Calixteinus contrasts figures 'in high relief' with figures 'in low relief' (Olson 2007: 463).

III.2 [16.8-10] ἐπὶ δὲ... εἰρήσεται. This passage presents two difficulties. The first has to do with what is meant by 'stretched surface' (ἐντεταμένην... ἐπιφάνειαν). The second concerns the fact that the manuscripts have εἴρηται in place of the conjectured εἰρήσεται (R. Schöne). Baldi 43^v n. 17 was the first to realise that the transmitted words καθάπερ εἴρηται are out of context, noticing that Hero has so far never mentioned either the πυργίον (which he translated as 'cupola' [19^v]; see also Schmidt 1899a: 353, with 'Kuppel') or its surface. After recording R. Schöne's conjecture, Schmidt in his app. crit. made reference to XIII.3 [46.4-5], because, as he explained elsewhere (LI), Hero there talks about the roof of the shrine (see also Murphy 41 n. 10). In truth, what Hero says in that passage is that 'κλμ should be a knob (πυρήν) placed on top of the shrine', which certainly implies, but does not directly state, that the knob rests on the summit of the roof (for more on this, see note on XIII.3 [46.4-6]). While not dismissing R. Schöne's conjecture as unlikely, Schmidt LI tentatively suggested that εἴρηται is a corruption of εἴθισται, a verb which he found at *Spir.* 250.2 (erroneously cited as 250.3). It is not clear, however, how εἴθισται was intended to improve the sense of the passage, all the more so since the expression ἐντεταμένην... ἐπιφάνειαν had not been properly understood. If we look closer at this expression, we find that Baldi 19^v was, as I will explain below, the only one to offer the correct interpretation of it ('superficie distesa'). Couture 246 would seem to have rendered the participle ἐντεταμένην as 'arcuatum', but it is difficult to see how the surface of a conical turret can be said to be 'bent like a bow'. Taking a more serious approach, Schmidt LI showed his approval of Brinkmann's interpretation of the expression ('eine anstrebende Oberfläche', namely 'a surface that extends upwards'), an interpretation arrived at by comparing Hero's words with Marc. Diac. *Vit. Porph.* 75.15-16 ἀνατεταμένον εἰς ὕψος (of a conical turret). In Schmidt's opinion, this interpretation would have the

advantage of allowing us to avoid assuming a lacuna in the text (more precisely, the lacuna which he suspected after I.2 [2.14] *τόπον*: the reference made by Schmidt LI to a suspected lacuna occurring here in the text must be corrected), but the words *καθάπερ εἴρηται* (which, in this case, should be understood as ‘as has just been said’, following Schmidt LI) would be redundant and pointless. Schmidt 353 himself, though, must not have been entirely convinced by Brinkmann’s comparison (indeed, the verb *ἐντείνω* cannot bear the sense of ‘stretching up’; cf. LSJ s.v.), as he mysteriously glossed his translation of *ἐντεταμένην* (‘überspannt’) with the term ‘überdacht’ (‘roofed’). The same caution has not been observed by Murphy 41 n. 40, who accepted what she erroneously believed to be a conjecture of Schmidt (*ἀνατεταμένην*, translated as ‘raised’ [13]), claiming that the word *ἐντεταμένην* does not make any sense at all. The verb *ἐντείνω* is used elsewhere by Hero with reference either to the stretching of the string of a bow (*Spir.* 186.21) or to the stretching or stringing of the spring of a catapult (for references, cf. note on II.6 [10.7-8]), but nonetheless it is in a different context – Hero’s *Definitions* – that we find the closest parallel to its usage here. Hero, *Deff.* 9 augments Euclid’s definition of a plane surface (*El.* 1 *Def.* 7 *Ἐπίπεδος ἐπιφάνειά ἐστιν, ἥτις ἐξ ἴσου ταῖς ἐφ’ ἑαυτῆς εὐθείαις κεῖται*) by adding the words *ὀρθὴ οὖσα ἀποτεταμένη* (as noted by Heath 1956: 171), and then goes on to explain that, if a straight line joins two points on this surface, the surface adapts itself completely to the said straight line, that is to say, it is uniformly stretched to match the entire line (see Giardina 2003: 281). In this way, Hero explains the Euclidean definition in similar terms to those he uses (*Deff.* 4) to explain Euclid’s definition of a straight line (*El.* 1 *Def.* 4, on which *El.* 1 *Def.* 7 is based), a line that lies evenly with respect to its points and which is, therefore, *ὀρθή... καὶ... ἐπ’ ἄκρον τεταμένη ἐπὶ τὰ πέρατα* (for the expression *ἐπ’ ἄκρον τεταμένη* said of a plane surface, cf. Procl. *in Euc.* 117.7-8; see Giardina 2003: 272-3). In the light of these definitions, particularly the first, there is little doubt that Hero simply meant to describe the cupola as having a plane surface and that, in order to do so, he used the middle of the verb *ἐντείνω* as a synonym for *ἀποτεταμένην* or *τεταμένην*. Thus, the meaning of the term is exactly the opposite of ‘bent’ or ‘raised’, and has also nothing to do with the function of the turret as the roof of the shrine. While we cannot determine whether Baldi in

some way understood Hero's terminology, we can conclude that he was right in retaining the original sense of ἐντεταμένην.

At this point, we can consider the words καθάπερ εἴρηται more carefully. The perfect εἴρηται cannot be right, because, as has been said, no previous reference has been made to the cupola. Schmidt did not give an explanation for his conjecture εἴθισται, but reading καθάπερ εἴθισται ('as is customary') would presuppose common knowledge of what 'stretched surface' refers to. At *Spir.* 250.2-3, the passage cited by Schmidt in support of his conjecture, Hero begins his description of the construction of a cupping glass (σικύα) by saying that the instrument should be οἷα εἴθισται γίνεσθαι τῷ σχήματι, but in this case the reader is invited to draw on general rather than specialised knowledge. Even without knowing the technical application of the term (LSJ s.v. σικύα II; Bliquez-Rodgers 1998: 238 with nn. 11 and 13), any reader would have been able to imagine the shape of an instrument bearing the same name as a fruit ('[bottle]gourd'). This is to say that Schmidt's conjecture does not seem to me well supported. The alternative envisaged by Schmidt in his app. crit. to 338.15 consists of assuming a lacuna after I.2 [2.14] τόπον. This possibility largely depends on his (mis)understanding of the previous lines as a precise reference to Hero's own mobile automaton rather than as a broad reference to various types of mobile automata (see further note on I.2 [2.9-10]). It is extremely unlikely, therefore, that a lacuna occurred there, even more so because it would unnecessarily interrupt the flow of the narrative. Following R. Schöne, I deem it more likely that the future εἰρήσεται corrupted into εἴρηται. This corruption is easy to explain palaeographically both in absolute and relative terms (when compared to εἴθισται). The difficulty remains that Hero makes no further mention of the cupola's surface. He was probably planning to return to the subject, but forgot to do so.

III.3 [16.11-12] Νίκη ἐκπεπετακυῖα τὰς πτέρυγας. The use of the verb ἐκπετάννυμι with the accusative of respect is unparalleled in Greek literature. A cultivated reader of Hero's time would have been reminded of the Meleagrean image of Eros spreading his wings: *AP* 5.179.10 = *HE* 4037 ἐκπέτασον ταχινὰς... πτέρυγας. As noted by Floridi (2007: 318), this imagery seems to have

been picked up and adapted by Strato of Sardis in *AP* 12.221.2 τὰς διφυεῖς ἐκπετάσας πτέρυγας (said of an eagle).

III.4 [16.18-20] **ξύματα... εἶναι**. I accept Schmidt's suggested deletion of τῶν σανίδων. In his app. crit. Schmidt rightly pointed to XII.4 [44.7] (τὰ τεκτονικὰ ξύματα) and XXVIII.5 [102.17-18] (ξύματα τεκτονικὰ ξηρότατα). Neither the expression ξύσμα(τα) τῶν σανίδων nor the variant ξύσμα(τα) τῶν σανιδίων, for instance, is found in any ancient source. When we find similar expressions elsewhere (ξύματα ξύλων or ξύματα ξύλων ξηρά: *Apollod. Poliorc.* 145.13 [where <ξηρά> is doubtfully suggested by Whitehead 2010: 88], *Hero Byz.* 217.1; ξύματα τῶν ξύλων καὶ καλάμων *vel sim.*: *Schol. anon. rec. Ar. Nub.* 130c beta, *Schol. rec. Ar. Nub.* 130a, *Schol. Tzetz. Ar. Nub.* 129a), the term ξύσμα is never qualified by the adjective τεκτονικός. This speaks in favour of the assumption that τῶν σανίδων is a later insertion, intended to explain the words ξύματα τεκτονικά. On two other occasions, XXVIII.5 [102.19-20] and [102.20], the term ξύσμα appears unqualified, but this seems to be due to the fact that these occurrences are preceded by XXVIII.5 [102.17-18].

On the efficacy of woodwork shavings over other (unspecified) combustibles, cf. XII.4 [44.7].

III.4 [16.20] **κατὰ δὲ κίονα**. The preposition κατὰ is here distributive, denoting spatial proximity: cf. *Lyr. Alex. Adesp.* 37.13 = Powell, *Coll. Alex.* 199 παῖδα κατὰ κρήνην (cited by LSJ s.v. B.II.1). There is no need, therefore, to add <ἕκαστον> after κίονα (R. Schöne). Nothing in the text warrants Murphy's interpretation that the Bacchantes are 'in line with' (13) each column.

III.4 [16.21-2] **Βάκχη διεσκευασμένη ὥς ἂν τις προαιρήται**. Prou 141 with n. 56 expressed his amazement at the sober decency of Hero's language here, but the verb διασκευάζω, in Heronian usage, has generally more to do with function than with appearance. In addition to I.3 [2.19-20] and XXII.1 [70.8-9], compare *Spir.* 86.5, 118.6, 116.3-4, 246.13-14, 304.2, where pneumatic components are cast into a particular form; for other, more aesthetically oriented expressions, cf. *Spir.* 126.2 and 280.5. As indirectly acknowledged by previous translators (see, in particular, Schmidt 353 and Murphy 13, both referring to the Bacchantes'

posture), a veiled reference to the demeanour of the Bacchantes as known from mythological accounts would have been out of context.

IV.1 [18.1-2] **Τούτων δὲ... <ῆμῶν>**. Schmidt is right in suggesting, however hesitantly, that the text should be supplemented with <ῆμῶν>. It seems apt to compare, as does Schmidt in his app. crit., the present passage with XIX.3 [62.7-8] ἀποστάντων ῆμῶν. ἀποστάντων can, indeed, be regarded as qualifying an unexpressed ῆμῶν, but the subject cannot be easily supplied from the context (see generally KG 2.81). Note the accumulation of genitive absolutes, each with a different subject. Examples of genitive absolute with unexpressed subject are frequent in BOOK TWO (πίναξ: XXI.1 [68.11-12], XXII.5 [72.14-15], XXII.6 [72.18-19] and [74.3], XXV.1 [84.12-13] [perhaps to be supplemented]; θύραι: XXII.4 [72.7]). Cf. also XIX.4 [62.13].

IV.1 [18.3] **ὑπάξει**. The scribe of **A** appears to have corrected ἐπάξει (also transmitted by **GM**) to ὑπάξει, a reading conjectured by Schmidt. **A**'s reading was recorded by Schmidt in his app. crit. as ἐπάξει, but the Teubner editor failed to notice that ἐ (in ἐπάξει) was originally written detached from the rest of the word. When making the correction, the scribe did not limit himself to changing the smooth breathing into the rough, but he conjoined the first two letters in one stroke, starting at the top of ε rather than at its bottom. Since normally initial epsilons in **A** are not conjoined with the letter that follows, this stroke seems to me to have been intended to correct ε to υ. Scribes copying from this manuscript could be easily deceived into writing ἐπάξει, as in **T**.

IV.1 [18.6] **ἐκπτυσιθήσεται**. The reading ἐκπτυσιθήσεται is inserted above the line by the second hand of **M** as a correction of ἐκπιτυσθήσεται, the latter also transmitted by **A**, **G^{pc}** and **T**. Three other manuscripts (**Aa**, **Bc**, **O**) have ἐκπτυσθήσεται. A similar kind of variation is found at IV.3 [18.17] ἀναπτυσιμός/ἀναπιτυσμός (**M/AG**) and at XIII.1 [44.15] ἀναπτυσιθῆναι/ἀναπιτυσθῆναι (**M/AGT**). The Teubner editor preferred to print the reading with better manuscript support in each of these places, and indeed we find separate entries in LSJ for the forms ἀναπιτύζω/ἀναπτυίζω, ἀναπιτυσμός/ἀναπιτυσμός, and ἐκπιτύζω/ἐκπτυίζω. In addition to comparing the

hapax legomenon ἀναπιτυσμός with ἀναπυτίζω (why not ἀναπιτύζω?), LSJ s.vv. assign different meanings to the verbs ἀναπιτύζω/ἀναπυτίζω ('cause to spirt out'/'spit up', 'spout up') on the one hand, and to the verbs ἐκπιτύζω/ἐκπυτίζω ('eject'/'spit out') on the other. What is interesting is that the verbs ἀναπιτύζω and ἐκπιτύζω are not attested outside the Heronian corpus. What is more, they are used in exactly the same way as ἀναπυτίζω and ἐκπυτίζω, namely, to describe a spurt of liquid (usually water). ἐκπιτύζω occurs only once more at *Spir.* 134.19, whereas ἀναπιτύζω appears in no other place than XIII.1 [44.15]. At all other times, we find forms of ἀναπυτίζω (*Spir.* 134.1 [J. G. Schneider : ἀναπιτίζοντι **AG** : ἀναποτίζοντι **T**], 212.18), ἀναπτύω (*Spir.* 76.10-11) and ἐκπυτίζω (*Spir.* 242.10, 242.11, 242.20, 246.1). The compound verbs ἀναπυτίζω and ἐκπυτίζω are formed, respectively, by the prepositions ἀνά and ἐκ and the verb πυτίζω. One fragment attributed by Theodoridis (1976: 351) to the first-century BCE grammarian Philoxenus of Alexandria gives us information on the verb πυτίζω (fr. *587 = Orion, *Etymologicum* s.v. πυτίζειν [134.20-1 Sturz] + *Et. Gen.* s.v. πυτίζω [= EM 697.57]; cf. Ps.-Zonar. *Lex.* s.v. πυτίζειν): πυτίζειν· παρὰ τὸ πτύω πτυτίζω ἐστὶν παράγωγον καὶ ἀποβολῇ τοῦ τ πυτίζω, etc. The text goes on to compare the derivation of πυτίζω from πτύω with that of πύξ from πτύσσω (πτύσσω → πτύξω → πτύξ → πύξ), but this portion is taken from the *Etymologicum Genuinum*, more precisely from the text of the tenth/eleventh-century CE manuscripts Vaticanus gr. 1818 (A) and Laurentianus S. Marci 304 (B). Similarly, the lemma πυτίζειν and the word πυτίζω are transmitted by either or both of AB (πυτίζειν B : πυτίζω A), while Orion's text (Par. gr. 2653, sixteenth century CE) gives, in their stead, πιτύζειν and πιτύζω. These forms do not seem right in the context of the etymological explanation, because the term πτυτίζω appears in Orion, too. One may suggest emending πτυτίζω to πιτύζω, but in that case the origin of the term would not be clear. Nor does it seem necessary to think, with Sturz (1820: 134 n. 50), that the whole of Orion's entry should be replaced by an etymological gloss on the verb πιτυλίζειν ('practise regular swinging of the arms', according to LSJ s.v. 1), for this has a quite different meaning from πτύζω/πυτίζω. All of this suggests that the forms ἀναπιτύζω and ἐκπιτύζω (and hence also ἀναπιτυσμός and ἐκπιτυσμός, the latter occurring once at *Spir.* 134.14) originated as scribal errors owing to iotacism no later than the thirteenth century CE, when the scribe of **A** copied the forms

ἐκπιτυσθήσεται, ἀναπιτυσμός and ἀναπιτυσθῆναι. The same mistake appears to have taken place in the transmission of the text of Philoxenus of Alexandria. I have, therefore, adopted the readings which are found in **M** (ἀναπιτυσμός is a *hapax legomenon*, too), thinking that each pair of LSJ entries should be merged into a single entry: ἀναπτυίζω, ἀναπιτυσμός and ἐκπτυίζω. Likewise, *Spir.* 134.14 (ἐκπιτυσμόν) and 134.19 (ἐκπιτύζεται) should be corrected.

IV.2 [18.9-10] αἱ δὲ περικύκλω... ναῖσκον. I follow Schmidt in adopting Diels' correction περικύκλω (against the manuscript reading περὶ κύκλω), since the adverb is generally written as one word in non-classical authors (cf. LSJ s.v. περίκυκλος). Baldi 20^r and Schmidt 355 correctly bring out the attributive position of the adverb. Couture 247 ('in gyrum circuibunt') and Murphy 13 ('will dance in a circle'), on the other hand, treat περικύκλω as an adverb modifying the main verb (their translations omit, respectively, χορεύουσαι and περιελεύσονται).

IV.2 [18.11-12] καὶ μετὰ... ζῳδίων. The words σταθέντων τῶν ἤχων have been variously emended and/or supplemented, mainly because of the strange use of the verb ἵστημι to refer to the noise of kettledrums and cymbals coming to an end. R. Schöne wondered whether the word ἤχων should be replaced by the word ἡχῶν, but the term commonly used by Hero to denote any kind of noise is ἦχος, not ἡχή (never found in Hero): see, for instance, IV.2 [18.10], XIV.2 [52.2], XX.3 [66.4], XX.4 [66.14], [66.15] and [66.18]; for further references, see Schmidt, *Supplementum* 160 s.v. ἦχος. A lacuna was suspected by H. Schöne and Brinkmann, who proposed similar conjectures: σταθέντων <τῶν ζῳδίων καὶ παυσθέντων> τῶν ἤχων (H. Schöne) and σταθ<εισῶν τῶν βακχῶν καὶ παυθ>έντων τῶν ἤχων (Brinkmann). H. Schöne's solution has the merit of being less invasive than Brinkmann's, even though the Bacchantes are never explicitly called ζῳδία in the treatise. The verb παύω, indeed, occurs twice in Hero in connection with sounds (*Spir.* 198.4, 200.18) and other six times to describe the interruption of a liquid flow (*Spir.* 42.6, 82.3 [libation], 182.11-12, 232.5, 258.14, 268.17), albeit never used in the aorist passive form. In the wake of Brinkmann's proposal, Schmidt tentatively suggested emending σταθέντων τῶν ἤχων to σταθεισῶν τῶν βακχῶν, citing in support IV.3 [18.20] σταθεισῶν

αὐτῶν [i.e. τῶν βακχῶν]. There are, however, two objections to this and other emendations. First, μετὰ ταῦτα already refers to the movements that have taken place up to this point, including the dance of the Bacchantes. Second, throughout IV.3 [18.16-20] there is stylistic *variatio*: note, especially, the use of the nouns ἀναπτυσιμός and ἔκχυσις in place of the verbs ἐκπυτίζω and ἐκχέω (cf. IV.1 [18.6-7]), the inversion of the syntactic roles of the verbs περιέρχομαι and χορεύω (cf. IV.2 [18.9-10]), and the prepositional phrase μετὰ ψόφου τυμπάνων καὶ κυμβάλων replacing the main clause of IV.2 [18.10-11]. There is therefore nothing to suggest that the text should contain the same (type of) reference as that of IV.3 [18.20], and one may even wonder why scholars did not feel the urge to supplement the latter passage on the basis of the words σταθέντων τῶν ἦχων. Perhaps we should content ourselves with emending σταθέντων to παυσθέντων. We may suppose that the first syllable of παυσθέντων had been omitted and that the resulting reading σθέντων was later corrected to σταθέντων through addition of τα. As much as I am tempted to print παυσθέντων, I prefer to keep open the possibility that Hero used the passive of ἵστημι in an unusual way.

IV.3 [18.15-16] ὁ ἔμπροσθεν... ἀνακαυθήσεται. The apparent change of the altar's position clearly depends on the fact that Dionysus has rotated. Neither of the altars moves around the figure of the god, contrary to what Murphy 14 believes: 'the altar that started behind Dionysus arrives in front of him'. **M** replaces ἀνακαυθήσεται (**AGT**) with ἀνακαμφθήσεται ('will bend back'), a similar misunderstanding. Cf. also IV.1 [18.4] and XII.1-4 [42.11-4.14].

Schmidt's proposed correction of the manuscript reading τῷ διονύσῳ is necessary, since ἔμπροσθεν governs the genitive only (LSJ s.v. II).

IV.3 [18.18] αἱ Βάκχαι χορεύσουσι. Manuscript **La** alone transmits the reading χορεύσουσι (already conjectured by Schmidt) against all the other manuscripts, which have χορεύουσι. The future tense agrees better with the context than the present (cf. the consistent use of the future throughout IV.1-4 [18.3-20.1]). On Schmidt's suggested χορεύσουσι at XVI.1 [54.9], see note on XVI.1 [54.8-9].

IV.3 [18.20-1] καὶ πάλιν... τόπον. I take πάλιν to refer to the genitive absolute σταθεισῶν αὐτῶν ('Wenn sie dann zum zweiten Male stehen bleiben', Schmidt

355) rather than to the main verb ἀναχωρήσει ('e di nuovo...ritornerassi la machina', Baldi 20^r). The automaton has not come back before, whereas the Bacchantes have already danced once (IV.2 [18.9-10]). The adverb has been omitted in Couture 247 ('*Quibus omnibus perfectis...machina sponte reverteretur*', my emphasis) and Murphy 14 ('when they stop the automaton will return').

M's reading ἀναχωρήσει is replaced in **AGT** by ἀναχωρίσει (which Prou 166 apparently corrected). The verb ἀναχωρίζω has the causative meaning of 'make to go back' (LSJ s.v.), whereas here we need the corresponding non-causative meaning of ἀναχωρέω (LSJ s.v. I.2). Reading ἀναχωρίσει would presumably mean taking τὸ αὐτόματον as the direct object rather than the subject and assuming that the subject is missing. But the whole point is that the automaton moves back on its own. The reading ἀναχωρίσει can be easily explained as having been caused by iotacism.

IV.4 [20.1] ἡ ἐπίδειξις. The term, as Cambiano (1994: 614) rightly pointed out, refers to the performance ('esibizione') of the automaton. For the same sense, cf. XXI.1 [68.6] and *Spir.* 174.8 (automatic fountain). Commenting on Hero's use of the term, Tybjerg (2003: 455) has drawn attention to its rhetorical meaning ('display speech'; cf. LSJ s.v. 3). Note, however, that during the Hellenistic and Imperial periods the word is used to refer not only to the exhibition of oratorical skills, but also to any kind of artistic performance (Pepe 2013: 272-3; cf. Van Liefferinge 2000: 150-1 with n. 10 [Delphic decrees]).

On the theatrical presentation (διάθεσις) as encompassing the ἐπίδειξις, see note on I.3 [2.19].

IV.4 [20.1-6] τοῖς δὲ εἰρημένοις...ὑπόνοιαν. This passage seems to serve a double purpose: to emphasise the sense of wonder inspired in the viewer by creating the illusion of self-motion, and to assert the identity of the automaton as a wholly mechanically operated device. Roby (2016: 146) has recently compared Hero's words μειζόνων...δημιουργούντος with Ph. *Bel.* 78.11-12, where great importance is attached to the appearance of Ctesibius' catapult as a means of achieving mechanical credibility (see Roby 2016: 144-5 with n. 118, drawing on Meissner 1999: 92): οὐ μόνον τῆς ἰσχύος, ἀλλὰ καὶ τῆς ὄψεως στοχαζόμενος

[sc. Κτησίβιος], ὅπως ὀργανικὴ φαίνεται. Hero's insistence on the need to follow specific measurements (and hence, more generally, to avoid too big dimensions in both types of automata) can, therefore, be read as setting out one of the preliminary conditions for the proper functioning of the device (*contra*, Cambiano 2011: 32; but see Cambiano 1994: 623). Needless to say, the dimensions given by Hero at III.1 (on which, cf. notes on III.1 [14.17-18], [14.20-16.1] and [16.3-4]) could easily forestall suspicion of a human operator inside the automaton (Murphy 41 n. 11).

Baldi 20^r, partly followed by Couture 247, took the words δεῖ φυλάσσεσθαι... ὑπόνοιαν to mean 'one must follow the mentioned dimensions to avoid the suspicion that *might* arise' ('bisogna serbare le dette grandezze per fuggir' il sospetto, ch'indi potrebbe nascere'), but the verb φυλάσσω is here in the middle voice (cf. LSJ s.v. C.II.1 for its use with the accusative) and cannot mean 'preserve', 'maintain' (a metaphorical meaning attested in the active: LSJ s.v. B.3; cf. B.6). Moreover, the term μέγεθος does not seem to refer to size in general (LSJ s.v. I.1), but to great size ('grossen Dimensionen', Schmidt 355), as implied by the concurrent use of μέτρον a few lines earlier and by μειζόνων... δημιουργοῦντος.

IV.4 [20.2] γὰρ γενηθέντων. The reading of **G**, **M** and **T** is to be preferred to that of **A** (γὰρ γε γενηθέντων), since the combination γὰρ γε is entirely, or almost entirely, avoided (Denniston, *GP* liii with n. 3). After γε two letters (perhaps νν) have been deleted. The scribe might have begun writing γενηθέντων, but made a mistake and repeated the ν (γενν-). He would thus have corrected his error and written the word γενηθέντων over again, albeit without deleting the remaining letters γε.

V-VI [20.8-26.5] *Forms of motion. Straight-line motion*

Hero introduces the main types of motion: straight-line, circular and rectangular (V.1-2). While the mechanism for straight-line motion is clearly presented as an improvement on the method (ὁδός, V.1) of the author's predecessors, circular motion (VII-VIII) and rectangular motion (IX-X) represent brand-new contributions to the field. Hero then proceeds to detail the configuration for forward motion (V.3-5), while also providing general information about the drive mechan-

ism of the automaton. There follows a description of backward motion (VI.1-2), including a mechanism for producing a pause between outbound and inbound journeys (VI.2). After suggesting a configuration for making the automaton travel forth and back many times (VI.3), Hero closes the section with a reference to a side view of the case (VI.4).

V.1 [20.9-10] **καὶ... ἐπικίνδυνον**. The καὶ is concessive and is used to emphasise the dangerousness and impracticality of the ancient system (Murphy 15, unlike other translators, omits it).

The combination *κακοπαθής τε καὶ ἐπικίνδυνος* is not found elsewhere. LSJ s.v. *κακοπαθής* II cite only this instance of the adjective in the sense of ‘troublesome’, ‘difficult’.

V.1 [20.11-12] **ὥς ἔστι... αὐτῶν**. Cf. XX.1 [64.6-7]. On the importance of practical testing (*πείρα*), cf. note on XI.6 [38.7-8].

V.2 [20.13-14] **ἡμεῖς δὲ... ἀκινδύνως**. In advocating the feasibility of achieving straight-line motion, Hero sets himself apart from and above his predecessors. The adverbial pair *εὐκόπως/ἀκινδύνως* (later expanded by the addition of the adverb *ξένως*, XX.1 [64.4-5]), emphasises the success of the method Hero is going to describe, in sharp contrast (*δέ*) with the terms *κακοπαθής τε καὶ ἐπικίνδυνον*. Perhaps the adverb *ἀκινδύνως*, with its privative alpha, implies that the locomotion of the automaton still involves some element of risk. McCourt (2012: 188) is clearly wrong to say that all other mechanisms of movement have no ‘guarantee’ attached. In addition to the passage cited above, cf. Hero’s remarks on rectangular (X.4 [34.23-4]) and snake-like (XI.11 [42.6-8]) motions.

V.2 [20.14-16] **ἔτι δὲ καὶ... φέρεσθαι**. The combination *ἔτι τε καὶ* is never found in Hero, unlike *ἔτι δὲ καί*, which occurs a total of 11 times. On these grounds, I have corrected the *τε* of the manuscripts to *δὲ*: cf. esp. XI.1 [36.3] and XX.3 [66.3] (both at the beginning of the sentence) and, after *τε-καί* coordination (as here), *Mech. Frag.* 2.1 = Papp. 1116.9 (*τε... καί*), *Metr.* 132.7-8 (*τε καί... καί*) and *Bel.* 74.1-3 (*τε καί... καί... καί... καί*). As far as the syntax is concerned, I have preferred to follow Schmidt in supplementing <ἔστι> after *ὥς*.

Hildebrandt's deletion of ὥς, on the other hand, does not seem quite right to me, because it presupposes a long-distance dependency between the ἔστι at the beginning of the previous subordinate clause and the infinitive φέρεσθαι (occurring twice, once here and once at the end of the sentence). It is helpful to compare the present passage with XI.1 [36.3-4] (ἔτι δὲ καὶ... δυνατόν ἐστι), where the main verb is repeated from the previous sentence.

In his app. crit. Schmidt suggested, somewhat hesitantly, that the article before πλινθίων should be emended to τι and that the words ἢ τὸ ζώδιον should be deleted. In support of his conjecture he cited V.3 [20.18-19] (ἔστω γάρ τι πλινθίων, etc.), but there the use of the indefinite pronoun is best explained by the geometric style of the description (see further note ad loc.). The proposed deletion of ἢ τὸ ζώδιον is more tempting. The main problem lies in the fact that no figure is said to move in a rectangular pattern (the verb περιάγω at XXIX.2 [104.24] suggests that the figure of Athena, just like the Bacchantes, could be made to move in a circular fashion), but perhaps we have to assume that the alternative was not intended to apply to the following clause. To further complicate matters, Schmidt 357 with n. 1, followed by Murphy 15, translated 'ein Kasten oder *eine* Figur' (my emphasis). The presence of the second definite article does not seem to be too problematic, if we concede that Hero was following his own train of thought.

V.2 [20.16-17] οὐ μὴν ἀλλὰ... φέρεσθαι. Or, more simply put, along a given rectangle. Curiously, Couture 247 took these words to mean that motion can be effected along an octagonal path ('per latera parallelogrammi octogoni'). This is even more surprising when we realise that at XI.1 [36.2] he understood the adjective ὀρθογώνιος correctly. For Hero's definition of rectangular parallelograms (based on Euc. 2 *Def.* 1, as implied by Giardina 2003: 199 n. 25), cf. *Deff.* 56 Τῶν δὲ παραλληλογράμμων ὅσα μὲν ὀρθογώνιά ἐστιν, περιέχεσθαι λέγεται ὑπὸ τῶν ὀρθῶν γωνίαν περιεχουσῶν εὐθειῶν, etc.

V.3 [20.18-19] ἔστω γάρ... $\overline{αβγδ}$. Hero begins his description of the configuration for forward motion in standard geometrical style. All manuscripts, except **La**, have the indefinite pronoun τι. Manuscript **La** has τὸ in its stead. One might be tempted to accept τὸ, since the case (πλινθίων) is by now well-known to the

reader. This, however, is the first of a series of similar geometric-like descriptions in which the definite article is generally omitted, as required by the formulaic nature of the geometrical language (see Schironi 2010: 349); but cf. XI.2 [36.6] ἔστω γὰρ τὸ πλινθίον, ἐν ᾧ εἰσιν οἱ τροχοί, τὸ $\overline{\alpha\beta\gamma\delta}$, etc. This is the only case in the treatise where the indefinite pronoun accompanies the first mention of either a geometrical or geometrised object; but similar examples are frequent in the *Pneumatica* (for instance, ἔστω τι ἀγγεῖον: e.g. *Spir.* 44.13, 112.16, 136.15; ἔστω σμηρυσμάτιόν τι: *Spir.* 54.1; Drachmann 1948: 82).

V.3 [20.21-22.1] **δύο τροχοὶ... φακοειδεῖς.** Various interpretations have been given to the words τὰς περιφερείας εἰργασμένοι φακοειδεῖς. Baldi 43^v-44^r n. 19, who was the first to acknowledge the proper meaning of the term φακοειδής ('lentil-shaped'; cf. Schmidt 357), brought to the reader's attention the distinction made by Pappus (more correctly, by Hero *ap.* Papp. 1126.21-1128.2 [= *Mech. Frag.* 2.5]) between two types of screw-thread: square (τετράγωνος) and lentil-shaped (φακοειδής or φακωτός, the latter being a more technical designation, according to Drachmann 1963a: 59). If we follow Pappus' account (cf. also *Mech.* 2.5, with Drachmann 1963a: 58-9), the square screw-thread is the one with perpendicular indentations, while the lentil-shaped screw-thread is the one with oblique indentations that converge to a single line. This equates to saying that the lentil-shaped screw-thread is much sharper than the square screw-thread (see Schmidt 1900: 287 with Figs. 71a-b). Thus, based on these features, Baldi concluded that what Hero had in mind were toothed wheels, and this because, as Hero himself pointed out (?), wheels of this kind had a better grip on the ground. Slightly more than a century later, Couture 247 ('orbis acute dentati') accepted this interpretation without any hesitation. In a more original way, Prou 160 thought of the physical properties of lentils and so provided the rim of wheels $\overline{\eta\theta}$ and $\overline{\kappa\lambda}$ with a 'surface rugueuse' ('rough surface'), despite what is said at II.3 [8.3-5]. Hero's primary goal would, once again, be a firm grip on the ground. Another, more eclectic approach has been taken by recent translators. Murphy 15 came up with 'wheels... with bevelled *edges*' (my emphasis), whereas McCourt (2012: 188) assigned a 'convex... shape' to the entire wheels. Given all this confusion over what the expression τὰς περιφερείας εἰργασμένοι φακοειδεῖς refers to, I would like to pay more attention to the distinction between the two

types of screw-threads. In order to obtain a clearer picture of what a lentil-shaped screw-thread should have once looked like, we need to turn to another source. After briefly dismissing the square screw-thread, Oribasius (*Coll. Med.* 49.4.56) explains that lentil-shaped (φακωτοῖ) screws (that is, screws with a lentil-shaped thread) ‘are those that have the roots (τὰς μὲν κοίλας ἔλικας) narrow at the bottom but wide at the top, and the crests (τὰς δ’ ὑπερεχούσας) broad at their base but tapered at the top, resembling a lentil cut in a half (ἡμιτόμῳ φακῶ)’. Therefore, the crests have the same shape as the roots but inverted, the inversion being explained by the very alternation between roots and crests. Oribasius’ explanation is interesting because it accords with some technical applications of the term φακοειδής. As noted by LSJ s.v., Ruf. *Onom.* 153.12 uses the adjective to refer to the lens capsule of the eye (which has the appearance of a convex disc), and Galen (*Meth. Med.* 10.448 Kühn) speaks of a knife with a ‘blunt and smooth lentil-shaped guard that projects at the margin’ (see Johnston-Horsley 2011: 217 Fig. 7 no. 4). In yet another context, Plu. *Aet. Rom.* 288b8-11 = VS 21 A 60.20-22 reports Empedocles’ view that the shape of the half-moon coincides with that of the lentil and the disc. This short survey allows us to make three observations about the meaning of the expression τὰς περιφερείας εἰργασμένοι φακοειδεῖς. First, the wheels cannot be toothed, since the adjectives φακοειδής and φακωτός denote not the alternation between roots and crests in a lentil-shaped screw-thread but their form: concave in one case, convex in the other. Second, there is no indication in our sources that the adjective φακοειδής ever meant ‘rough’ or ‘bevelled’. Three, McCourt (2012: 188) was right to think of a convex shape, given what we know about wheel-making in antiquity (see Weller 1999; Stieber 2006: 585, 587-8, on E. *Ba.* 1066-7). This, however, does not characterise the wheels as a whole, but only their circumferences or rims. What Hero almost certainly meant was that the outer surface of the wheel rim should be worked so as to be convex.

V.3 [22.2-3] καὶ <ἔστω>... ἐπειληθήσεται. I deem it necessary to supplement the text with Schmidt’s proposed <ἔστω>, since the main verb is missing. Previous translations, including McCourt’s (2012: 188), appear to supply the third-person singular imperative form from the ἔστωσαν of the preceding sentence, but the presence of coordination (καὶ αὐτὴ συμφυῆς, etc.) suggests that a verb is needed.

Moreover, it is extremely rare, if not impossible, at least in the *Automata*, to find omission of third-person imperatives, especially when they are used to introduce the description of an object.

Hero's ἐξελίκτηρα (literally 'unwinder', following Keenan-Jones-Ruffell-McGookin 2016: 167) has first attracted the attention of Prou 161 with n. 143. Unlike most scholars, who understood the term as referring simply to a 'cylinder', Prou 161 n. 143 acknowledged that the ἐξελίκτηρα is in fact a 'spool' (see also Drachmann 1948: 145-6, on *Spir.* 298.7-302.3, where the term occurs thrice) or 'bobbin' ('un *dévidoir*, une *bobine*'). Rather than being derived from the noun ἑλιξ (as maintained by Prou), the term (which is never attested outside Hero) is, more correctly, derived from the verb ἐξελίσσω (see already Keenan-Jones-Ruffell-McGookin 2016: 173). Prou observed that the ending -τρα indicates that the object has a rectilinear shape. This is a very curious remark, given that the feminine suffix -τρα, and the corresponding neuter form -τρον, can be used to denote all sorts of instruments (Chantraine, *Form.* 330-3), regardless of their shape. Add to this that Hero's ἐξελίκτηρα is probably cylindrical (in addition to the translations, see Baldi 20^v unnumbered Fig.; **Fig. 5**; the ἐξελίκτηρα cannot be distinguished from the axle in Schmidt 356-7 Figs. 83a-b and Murphy 16 Fig. 2), as it is used to 'unwind' the cord from the wheel axle. More recent attention has been drawn to the origin and function of the ἐξελίκτηρα. Keenan-Jones-Ruffell-McGookin (2016: 172-4) have shown how Hero's ἐξελίκτηρα, which can, perhaps, be traced back to Philo (also compare Philo's mention of a wooden ἐξελίκτηρον for storing, or assisting with reinstallation of, catapult spring-cords: Ph. *Bel.* 67.22-5), functions as an inverted windlass ('un-windlass', in their terminology). While the windlass, as described by Hero, *Mech. Frag.* 2.1 = Papp. 1118.2-10 (ἢ καὶ... ἄξονι del. Hultsch), lifts heavy weights using a smaller force, the axle and ἐξελίκτηρα assembly is made to rotate by a cord being unwound under the impulse of a light weight. As stressed by Keenan-Jones-Ruffell-McGookin (2016: 174), the most probable function of the ἐξελίκτηρα, with its position at the centre of the axle (κατὰ μέσον τὸν ἄξονα), was to reduce the inclination angle of the cord and, therefore, to minimise the resulting loss of force. If Hero did derive the term ἐξελίκτηρα from Philo, as might well be the case, the employment of the feminine rather than neuter suffix need not be overemphasised (Keenan-Jones-Ruffell-McGookin 2016: 173), all

the more so when we consider the overlap of meaning between -τρον and -τρα (Chantraine, *Form.* 333). The term ἐξελίκτρα also occurs in BOOK TWO, where it refers to the bobbin used to unwind a scroll of papyrus (seafaring scene): XXVI.7 [94.20], XXVI.8 [96.6], XXVIII.2 [100.13-14], XXVIII.3 [102.2]. The etymology of the term is clearly brought out by XXVI.8 [96.5-7] περιελήσας οὖν σπάρτον περὶ τὴν ἡζ̄ ἐξελίκτραν, ὅση μέλλει ἐξελίσσειν τὸν χάρτην, etc.

V.4 [22.4] **τύλος ὁ ξ̄**. Schmidt was no doubt right in correcting the manuscript reading $\overline{\nu\xi}$ to $\overline{\xi}$ (not just here but also at [V.4] 22.10 and [VI.1] 24.1), since $\overline{\nu}$ already denotes one extremity of the ἐξελίκτρα. Furthermore, a knob is never designated by more than one letter. The reading of **M** before correction (στύλος) is obviously a mistake, for it makes no sense to have a ‘pillar’ attached to the ἐξελίκτρα.

V.4 [22.5-7] **τροχὸς... σφόδρα**. This is clearly a non-driving wheel in that there is no cord connecting its axle to the counterweight. It is labelled $\overline{\rho\pi}$ in the manuscripts, but $\overline{\rho}$ is already used for one of the points of the wheel’s frame ($\overline{\rho\sigma\tau\upsilon}$). It is, once again, necessary to accept Schmidt’s correction (see previous note). The reading $\pi\eta\gamma\mu\alpha\tau\iota$, which is transmitted by **G** and **M^{pc}**, is surely right as against $\pi\eta\gamma\mu\alpha\tau\alpha$ (**A^{cp}**), because $\acute{\epsilon}\nu$ requires the dative. Manuscript **Pg** bears in the margin the plural $\pi\eta\gamma\mu\alpha\sigma\iota$, which does not make sense in the context. The wheel is, in fact, set within its own frame, as illustrated by the manuscript diagrams (see **Fig. 4a**). The plural also does not agree with the following $\tau\hat{\omega}\ \overline{\rho\sigma\tau\upsilon}$. Πολεούμενος (**AGT**) fits better here than πορευόμενος (**M**). The middle-passive voice of the verb πορεύω (‘to be driven’, ‘go’) never refers to the automaton’s wheels, only to the $\pi\lambda\iota\nu\theta\acute{\iota}\omicron\nu$ as a whole. By contrast, the verb πολεύω is used elsewhere in the middle-passive voice with regard to a screw (or its extremities) turning on dowels (X.2 [34.10]) or within διαπήγματα (*Mech. Frag.* 2.6 = Papp. 1128.20-3).

V.4 [22.7-9] **οὕτως δὲ... μέρος**. The same emphasis on balance and equilibrium appears at VII.3 [26.18-19] οὕτως οὖν τετάχθωσαν οἱ τροχοὶ τῇ θέσει, ὥστε ἐστὸς ἐπ’ αὐτῶν τὸ $\pi\lambda\iota\nu\theta\acute{\iota}\omicron\nu$ ἰσορροπεῖν. Cf. also VIII.2 [28.12-13].

V.5 [22.12-13] **σύριγγος... πλινθίων**. As correctly pointed out by Murphy 41 n. 12, the tube is placed at the centre of the case (between the four columns) for the sake of balance and to facilitate attachment of the cords to the counterweight. Its designation as τετράγωνος ('viereckige', Schmidt 359) probably refers to a rectangular shape (so Murphy 15) rather than to a square shape (so Baldi 20^v; Couture 248; Prou 162). When referring to a square, Hero sometimes uses the adjective together with ἰσόπλευρος (*Deff.* 51 and 100; cf. XXVI.2 [90.15]). The rectangular shape here has the advantage of allowing maximisation of the space between the four columns. In any case, it is clear that the tube is not conceived as cylindrical, as supposed by Landels (1978: 203). It is not until IX.5 [32.7-8] that the reader is informed of the hole at the bottom of the tube, but the missing information can easily be reconstructed from II.9 [12.10-11].

V.3 [22.13-14] **τροχίλου**. Hero's τροχίλος is a single-sheaved pulley, which is used exclusively to change the direction of the force (Keenan-Jones-Ruffell-McGookin 2016: 173). On the term, see especially Rambaldi (1999: 77 with n. 51), with further bibliography.

V.5 [22.16-17] **ἐάν... σπάρτον**. I adopt Schmidt's suggested emendations of κάτω φέρεσθαι to καταφέρεισθαι and of τείνει to τενεῖ. In support of the first emendation, Schmidt (app. crit. ad loc.) cited five occurrences of the verb καταφέρομαι (II.9 [12.12], VI.1 [24.4], IX.4 [32.3], XV.3 [52.17], XV.4 [54.7]): of these, the first three refer to the fall of the counterweight, and the other two to the fall of the wreath. Indeed, the usual verb for the descent of the counterweight is καταφέρομαι (in addition to the passages cited, cf. XI.3 [36.17] and XIII.9 [50.13]). The adverb κάτω occurs elsewhere in Hero only once modifying φέρομαι (*Spir.* 122.9), but the resulting expression refers to a pipe bearing downwards, not to a body falling down. The second emendation (anticipated by Baldi 20^v) is necessary too, as Hero shows a strong tendency to prefer future forms in the apodosis of conditional clauses of this type (for two exceptions, cf. Stereom. 1.43.2a and 2.3.1).

I take the subject of the apodosis to be the same as the subject of the protasis (cf. XIII.8 [50.1], XXIII.3 [74.18-19]), rather than assuming an unexpressed

‘counterweight’ (so Couture 248; Schmidt 359). I do not understand why Murphy 15 and McCourt (2012: 188) translate *ἐάν τις* as ‘if anything’.

VI.1 [22.22-24.3] *ἐπειληθείσης... ἐξελίκτραν*. As reiterated at VI.2 [24.10-15], it is by changing the direction of winding of the cord that the automaton can travel forth and back (see also Keenan-Jones-Ruffell-McGookin 2016: 173). Prou 166-8 devised a system whereby forward and backward motion would be brought about by the winding and unwinding of two distinct cords, each looped around the knob *ξ*. During the time when the first cord would unwind from the *ἐξελίκτρα* and thus cause the automaton to move forward, the second cord would instead wind in the opposite direction. This would then be followed by the unwinding of the second cord and, consequently, by the backward motion of the automaton. Prou 168 even specified that the second cord should be longer than the first, arguing that this is what Hero warns his readers about at VI.2 [24.9-14]. What Hero says there, however, is only that a pause can be effected between the forward and backward motions by forming a slack hank of cord to be glued on the *ἐξελίκτρα*. This does not represent a warning (*‘précaution indispensable’*, in Prou’s words) but an alternative or additional configuration to that illustrated here (as also signalled by OPENING E, *ἐάν δὲ βουλώμεθα*). It is all the more significant that only one cord is mentioned in that context too. Schmidt, *Supplementum* 139 was therefore right in condemning Prou’s addition <ἄλλη> after *περιτεθείσα*, for having two cords does not accord with the author’s intentions.

The reading transmitted by **M** (*ἐπικείσθω*) in place of *ἐπειλείσθω* (**AGT**) makes little or no sense, even assuming that Schmidt’s suggested <ἐπειλήσει> should be replaced by something else (but what?). From what follows (see above), it is clear that the cord has to be alternately wound and cannot be ‘placed contrariwise in/on the preceding <winding>’ (taking *ἐπικείμεαι* with the following dative, cf. LSJ s.v. esp. I.2 and II.1). Schmidt rightly based his proposed addition <ἐπειλήσει> on VI.1 [24.5] *τὴν πρώτην ἐπέλυσιν*. The reading was probably omitted owing to its proximity to *ἐπειλείσθω*. In his app. crit. Schmidt added ‘minus placet ἢ pro τῇ’, but it is not immediately obvious whether he meant ἢ πρότερον <ἐπειλήσει> (which does not sound right to me) or simply ἢ πρότερον (occurring only once in Hero: *Spir.* 38.1 *πληρέστεροι ἢ πρότερον*). Translators such as Baldi 21^r, Couture 248 and McCourt (2012: 189) must have

felt some difficulty here, since they omitted translating τῇ πρότερον. Despite not printing his own addition in the Greek text, Schmidt 359 ('Umwicklung') adopted it in his translation.

VI.1 [24.3-4] κρίκου συνεχομένου αὐτῇ. In his app. crit. Schmidt proposed emending συνεχομένου to συγκεκοινωμένου ('firmly fastened') on the basis of XIII.9 [50.10] ὁ δὲ συγκεκοινωμένος τῷ βάρει κρίκος. The verb συνέχω is generally used by Hero in its primary meaning of 'hold together', 'confine' (XV.3 [52.20], XXV.6 [88.8], *Bel.* 83.3, 107.4, *Dioptr.* 196.18, 196.28, *Spir.* 310.10), but can also refer to liquids being held back (*Spir.* 58.14, 202.3, 274.12). On three other occasions (*Bel.* 99.6, 99.8, 100.7), it is found in the passive voice in connection with the joining or fitting of components together. Schmidt's proposed συγκεκοινωμένου is therefore unnecessary. Cf. also *Spir.* 326.9-10 συνέχεσθαι δὲ τὴν κεφαλὴν τῷ σώματι.

VI.2 [24.10-11] ἐπειλήσαντες...τύλον. The aorist participle περιβαλόντες is preferable to the present περιβάλλοντες (**Pa** and **Pf**) because, just like ἐπειλήσαντες, it serves to indicate anteriority to the future action of the main verb ἐπειλήσομεν (on Brinkmann's conjecture, see following note).

VI.2 [24.12-15] οὐκ εὐθέως...λείαν. Unlike the Teubner editor, I have adopted Brinkmann's conjectured ἐπειλήσομεν in place of ἐπειλησόμεθα. The verb ἐπειλέω is never used by Hero in the middle voice, which strongly argues for ἐπειλησόμεθα being a mistake. Presumably this reading arose under the influence of the preceding βουλόμεθα. As recorded in Schmidt's app. crit., Brinkmann deleted the following ἐπειλήσομεν as a corrective gloss on ἐπειλησόμεθα. This must be right, because the (deleted) ἐπειλήσομεν appears out of context. The participle ἐπειλήσαντες and the main verb ἀποδώσομεν presuppose an unexpressed object such as τὴν σπάρτον (cf. also VI.1 [24.1-3]), whereas ποιήσαντες and προσκολλήσαντες are clearly construed with the direct object μηρυμάτιον. Accepting ἐπειλήσομεν would thus imply that the hank is wound on the ἐξελίκτρα, which is not consistent with the purpose of the cord slackenings (see note on II.10 [14.2-3]). Prou 168 with n. 156 quoted the Greek text from the *ed. princ.*, but instead of writing the erroneous προσκόλυσαντες (in lieu of

προσκολλήσαντες), he wrote the equally erroneous προσκωλύσαντες (from *προσκωλύω?) and curiously translated it as ‘appliqué’. I was unable to find such reading in any of the manuscripts consulted by Prou, which means that it is either an unhappy conjecture or a trivial mistake.

As for Schmidt’s tentatively suggested μηρυμάτια, it has been conjectured on the grounds that the plural of the primitive form μήρυμα occurs at II.11 [14.4] and VI.3 [24.20]. However, I would like to raise two objections. First, the use of the plural in the first passage can be explained by the fact that Hero there is making a general observation. Second, the context of the second passage is quite different from the present one. There Hero mentions the possibility of performing repeated forward and backward motion (which entails the occurrence of several pauses), whereas the current configuration is for the automaton to move, stop and come back. Unlike with the configuration for repeated motion, there is no need to form multiple hanks here, because the automaton is configured to make only one pause.

VI.2 [24.15] καὶ ἔσται τὸ προκείμενον. Perhaps we should write καὶ <οὕτως> ἔσται τὸ προκείμενον, as at *Spir.* 128.2-3. Cf. VI.2 [24.8] καὶ οὕτως ἔσται ἡ ἀποπορεία, picked up and varied by VI.2 [24.10]; but cf. *Metr.* 148.2 and 184.10. For the phrasing, cf. XI.5 [38.6].

VI.3 [24.16-20] ἐὰν δὲ καὶ... προαιρώμεθα. This passage has been suspected of being an interpolation by Schmidt LII. The main reason which Schmidt implicitly adduced in support of his opinion is that in ch. XIX, the only other place in the text where Hero speaks of outbound and inbound journeys, there is no hint as to how to repeat the movements. The aim of ch. XIX, however, is to illustrate the use of two counterweights and two tubes as an improved alternative to the more traditional and perhaps safer single-counterweight system (Introduction, p. cxiv). A further point made by the previous editor is that the configuration for repeated forward and backward motion requires the placement of multiple knobs on the ἐξελίκτης. This is not necessarily true. A configuration with only one knob is still possible, provided that the latter is sized to receive multiple cord loops. To this must be added that the section begins with a variation of OPENING E (ἐὰν δὲ καὶ... βουλώμεθα), a fact that strongly speaks against interpolation. As

already suggested by Olivieri (1901: 432), Hero is simply elaborating upon the configuration of VI.2 [24.9-15], albeit without giving full practical details.

More problematic are the concluding lines of the passage. The text, as it stands in the manuscripts, reads τοὺς τῶν δαιμόνων χρόνους ποιήσομεν διὰ τῶν μηρυμάτων, etc. The reference to certain δαίμονες is problematic because Hero does not use the term anywhere else. Three different interpretations have been proposed, none of them convincing. The first, and oldest (Baldi 44^r n. 20), is that Hero might have meant to refer to Greek planetary gods (or, presumably, figures thereof) who, introducing themselves into the automaton, would have mimicked the motion of the planets. While such an interpretation is clearly absurd, it demonstrates that despite his apparent mistranslation of the term ('Tempij' [21^r] instead of 'Tempi'; cf. 'templa', Couture 249), Baldi understood the text correctly. The second interpretation (Schmidt 361-3 n. 2) relies upon the editor's choice to translate his tentative conjecture χοροὺς for χρόνους. Schmidt seems to think that δαιμόνων refers to the Bacchantes, insofar as they are the only dancing figures in the automaton. As he points out, the dances take place while the automaton is not moving and the cord slackenings are being taken up. This is no doubt true, but it is not clear how such a reference would fit within the context. Schmidt's interpretation is, moreover, made less plausible by the fact that the female followers of Dionysus are designated as δαίμονες only twice and in late sources (Bas. Caes. *Epist.* 74.1.21 and Ps.-Nonnus, *Comm. in Greg. Naz. Serm.* 39.4 = 223.21-3 Nimmo Smith). The third interpretation (Murphy 41 n. 13) seems to take 'deities' to mean Dionysus. That the term refers to the god, and perhaps also to the Nike, is a possibility, but a slack hank of cord has just been mentioned in connection with the pause of the automaton (VI.2 [24.12]). Perhaps the best way to make sense of the transmitted text is to suppose that the phrase τοὺς τῶν δαιμόνων χρόνους originated in a separate source. The term δαίμων could thus refer to such figurines as might have been described in Hero's now lost *Zύγια* (Introduction, pp. lxvii-lxviii with n. 108). However, the fact that the term never occurs in Hero (or in other mechanical writers) seems to suggest otherwise. This naturally leads to the assumption that the text was corrupted and that δαιμόνων should read δὲ μονῶν (Brinkmann). This conjecture gives excellent sense and is palaeographically plausible (δὲ μονῶν > δαι μονῶν > δαιμόνων), although it produces an awkward word order (*contra*, Brinkmann *ap.*

Schmidt's app. crit. to δαιμόνων). Denniston, *GP* 186 records only one instance of δέ immediately following two definite articles (E. *Tr.* 848 τὸ τῶς δὲ [Murray : τᾶσδε codd.] λευκοπτέρου), but this is clearly treated as an exception. The most likely scenario is that δὲ was interpolated into the text. Perhaps a scribe, thinking of the halt state of the automaton (VI.2 [24.9-10]), corrected τῶν to τῶνδε (but in fact he should have more correctly written τῶνδε τῶν μονῶν). The demonstrative pronoun was probably later misread as τῶν δὲ (incorrect word-division), which subsequently led to the corruption of δὲ μονῶν. On these grounds, I have deleted δὲ. The resulting phrase (τοὺς τῶν μονῶν χρόνους) has a parallel in Gal. *Nat. Fac.* 3.7 = 220.5 Helmreich τῆς μονῆς ὁ χρόνος (of food remaining in the stomach).

VI.4 [26.1-5] νοείσθω... ε̄. Hero does not merely assign a different set of points to his configuration, as he does later on in the case of rectangular motion (VI.4 [32.19-20]). Rather, he also gives a side elevation of the case, as can be seen in the accompanying diagram (**Fig. 6a**). Contrast VI.4 [20.18-22.2], with **Fig. 4a** (plan view). As pointed out by Drachmann (1972: 489), nowhere else does Hero give two elevations of the same device.

Schmidt was right to delete δὲ after τροχίλον, both because it repeats the preceding δέ, and because of its odd position. All manuscripts except **F** have the participle περικειμένην. **F** has περικείμενον, which probably arose under the influence of the preceding τροχίλον. This reading cannot be right, since it is the cord that is wound around the pulley. I have therefore corrected περικειμένην to περικειμένη to make the participle agree with the subject σπάρτος.

VII-VIII [26.6-30.2] Circular motion

Hero's treatment of circular motion shows a high degree of geometrisation. As Roby (2017: 533) acutely notes, the automaton is reduced to 'an imaginary mathematical "skeleton" of itself'. Ch. VII describes the configuration for circular motion, whereas ch. VIII lays the mathematical principles of motion itself. The configuration consists of three wheels mounted on two axles which are set at an angle. From VIII.1 οἱ δὲ ε̄ζ, θκ, πρ τροχοὶ ἐν κώνοις εἰσὶ δυσὶν, ὧν βάσεις μὲν οἱ ε̄ζ, πρ κύκλοι, it is clear that the outer wheel ε̄ζ ought to be made bigger than the inner wheel θκ (see also Murphy 41 n. 15). This results in a fixed turn-

ing radius, no matter how large the latter is (VII.1 $\tau\iota\varsigma\ \eta\ \overline{\alpha\delta}$). For more on this configuration, see McCourt (2012: 190-2).

VII.1 [26.7-8] $\xi\sigma\tau\omega\ \gamma\acute{\alpha}\rho\ldots\overline{\alpha\beta\gamma}$. Schmidt's proposed emendation for $\tau\omicron$ must be accepted because the article before $\overline{\alpha\beta\gamma}$ has to agree with $\kappa\acute{\upsilon}\kappa\lambda\omicron\varsigma$ (see generally Schironi 2010: 347). Schmidt in his app. crit. correctly cited XII.2 [42.15] $\delta\ \overline{\alpha\beta\gamma\delta}$ [sc. $\beta\omega\mu\acute{\omicron}\varsigma$]; but cf. also, for instance, *Metr.* 54.9-10, *Spir.* 158.8-9.

VII.1 [26.8-9] $\langle\pi\rho\acute{\omicron}\varsigma\rangle\ \tau\acute{\alpha}\upsilon\tau\eta\nu\ldots\overline{\epsilon\alpha\zeta}$. When the adjective $\acute{\omicron}\rho\theta\acute{\omicron}\varsigma$ is used to express a relation of perpendicularity, it is followed by $\pi\rho\acute{\omicron}\varsigma$ + accusative (LSJ s.v. $\acute{\omicron}\rho\theta\acute{\omicron}\varsigma$ I.b; cf. also Mugler, *Dictionnaire* s.v. $\acute{\omicron}\rho\theta\acute{\omicron}\varsigma$ 2-3), not by the dative ($\tau\acute{\alpha}\upsilon\tau\eta$, following the manuscripts): see, with reference to a straight line, *Deff.* 115.2, *Dioptr.* 232.22, 290.17-18, 292.3-4, 292.4-5 and *Metr.* 96.2-3; for further references in Hero's *Definitions* and *Stereometrica*, see Heiberg (1914: 259) s.v. $\acute{\omicron}\rho\theta\acute{\omicron}\varsigma$. I have therefore emended $\tau\acute{\alpha}\upsilon\tau\eta$ to $\tau\acute{\alpha}\upsilon\tau\eta\nu$ and added $\langle\pi\rho\acute{\omicron}\varsigma\rangle$ in front of it. In his app. crit. Schmidt hesitantly suggested replacing $\acute{\omicron}\rho\theta\eta$ with the prepositional phrase $\pi\rho\acute{\omicron}\varsigma\ \acute{\omicron}\rho\theta\acute{\alpha}\varsigma$ [sc. $\gamma\omega\nu\acute{\iota}\alpha\varsigma$], but this is clearly a more invasive emendation. For $\pi\rho\acute{\omicron}\varsigma\ \acute{\omicron}\rho\theta\acute{\alpha}\varsigma$ + dative (very frequent in Hero), see, for example, VII.2 [26.15] and XXVII.4 [100.3], already cited by Schmidt in support of his suggestion; cf. also XXVII.4 [100.4].

VII.2 [26.12] $\tau\hat{\omega}\ \delta\grave{\epsilon}\ \mu\epsilon\gamma\acute{\epsilon}\theta\epsilon\iota\ldots\overline{\alpha\eta}$. Line $\overline{\alpha\eta}$, as has been correctly noted by Murphy 41 n. 14, corresponds to the portion of the axle contained between wheels $\overline{\epsilon\zeta}$ and $\overline{\theta\kappa}$. The whole axle, in fact, appears to be $\overline{\tau\upsilon}$ (VII.2 [26.16-17]). This distinction is also shown in some diagrams, such as that of **A** (Fig. 7a). For $\acute{\alpha}\xi\omega\nu$ as denoting the 'axle shaft', cf. XIII.8 [50.4].

VII.2 [26.13] $\eta\ \overline{\eta\theta\kappa}$. In his app. crit. Schmidt proposed emending $\overline{\eta\theta\kappa}$ to $\overline{\theta\eta\kappa}$, certainly because $\overline{\eta}$ represents the midpoint of the line. The suggestion makes good sense in terms of its consistency with the preceding $\overline{\epsilon\alpha\zeta}$ (VII.1 [26.9]). I have, however, preferred to retain the best attested reading, since its letters are arranged in alphabetical order (on this tendency, see Roby 2017: 523). **M** and manuscripts **Ld** and **Ph** (*in margine*) have, respectively, $\overline{\theta\kappa}$, $\overline{\eta\theta\eta}$ and $\overline{\eta\kappa\theta}$. The first two readings are clearly errors: $\overline{\theta\kappa}$ arises from haplographic omission of η ,

whereas $\overline{\eta\theta\eta}$ from confusion between minuscule η and κ . The reading $\overline{\eta\kappa\theta}$ probably represents a failed attempt to correct $\overline{\eta\theta\kappa}$.

VII.2 [26.13-14] $\tau\acute{o}\ \delta\grave{\epsilon}\ \pi\lambda\iota\nu\theta\acute{\iota}\omicron\nu\ldots\overline{\alpha\delta}$. It is probably unnecessary to add $\langle\pi\lambda\epsilon\nu\rho\acute{\alpha}\nu\rangle$ after $\overline{\nu\xi}$, as doubtfully suggested by Schmidt in his app. crit (but see already Baldi 22^v; Couture 249). $\tau\grave{\eta}\nu\ \overline{\nu\xi}$ can simply be understood as referring to the line $\overline{\nu\xi}$ in the accompanying diagram.

VII.2 [26.15] $\acute{\eta}\ \overline{\pi\rho}\ldots\overline{o}$. Both Murphy 17 and McCourt (2012: 190) have interpreted the phrase to mean that $\overline{\pi\rho}$ bisects $\overline{\delta o}$ below ($\acute{\upsilon}\pi\acute{o}$) the point \overline{o} . But the participle $\tau\epsilon\mu\nu\omicron\mu\acute{\epsilon}\nu\eta$ must be understood as passive (so Baldi 22^v; Couture 249; Schmidt 363) rather than middle. Moreover, it would be pointless to say that a bisection occurs below a point denoting the extremity of a line. Murphy 17 Fig. 3 shows $\overline{\pi\rho}$ bisecting $\overline{\delta o}$ into two unequal parts, but $\delta\acute{\iota}\chi\alpha\ \tau\acute{\epsilon}\mu\nu\epsilon\iota\nu$ signifies geometrical bisection (for instances, see Mugler, *Dictionnaire* s.v. $\tau\acute{\epsilon}\mu\nu\epsilon\iota\nu$; cf. VIII.2 [28.13-15]). McCourt (2012: 191 Fig. 2), on the other hand, has no point \overline{o} .

Schmidt's tentative emendation $\tau\grave{\eta}\varsigma\ \overline{\delta o}$ (anticipated by Baldi 22^v) for $\tau\omicron\upsilon\ \overline{o}$ is tempting but perhaps unnecessary. The line $\overline{\pi\rho}$ is in fact bisected by the line $\overline{\delta o}$. Taking \overline{o} as the point of bisection ($\delta\iota\chi\omicron\tau\omicron\mu\acute{\iota}\alpha$, cf. VII.1 [26.10]) implies that one of the extremities of the axle of $\overline{\pi\rho}$ coincides with the centre of the wheel ($\overline{\pi\rho}$ being the wheel, $\overline{o\chi}$ its axle: VII.2 [26.16-17]), which is clearly absurd. However, some manuscripts diagrams, including that of **A** (Fig. 7a), show the point \overline{o} (not the 'line' \overline{o} , as Couture 249 has it) a little further away from $\overline{\pi\rho}$, but still inside the circumference passing through $\overline{\alpha}$ (which, indeed, is not one of the extremities of the axle of $\overline{\epsilon\zeta}$). This might be taken to reflect the original arrangement for two main reasons. First, the cones within which are inscribed $\overline{\epsilon\zeta}$ and $\overline{\pi\rho}$ are said to describe more than one circle (VIII.2 [28.7-11]). If $\overline{\pi\rho}$ were as distant from the centre as $\overline{\epsilon\zeta}$ (as illustrated in Baldi 22^r unnumbered Fig. and McCourt 2012: 191 Fig. 2), the wheels would describe the same circle. Second, placing \overline{o} on or outside the circumference (see, respectively, Murphy 17 Fig. 3 and Baldi 22^r unnumbered Fig.) would probably result in the point itself, and hence the pivot (VII.3 [26.19-20]), being too distant from the wheel. Speculatively speaking, if Hero was describing the diagram as we find it in **A**, he might have been

influenced by the proximity of \bar{o} to $\bar{\pi\rho}$. The text could therefore be not corrupt, but simply inaccurate.

VII.3 [26.19-20] οἱ ἄρα κνώδακες... σημείοις. The term κνώδακες has been repeated and then corrected in the margin of manuscript Par. suppl. gr. 11, where we read ~~κνώδακες~~ πυελίδες. These words have been written in a different ink, perhaps by a later hand. There seems to be no reason to adopt the reading πυελίδες instead of κνώδακες. The points $\bar{\tau}$, $\bar{\upsilon}$, \bar{o} and $\bar{\chi}$ represent the extremities of the axles of the wheels $\bar{\epsilon\zeta}$, $\bar{\theta\kappa}$ and $\bar{\pi\rho}$ (VII.2 [26.17]), and are therefore correctly identified with the pivots of the axles. Furthermore, saying πυελίδες τῶν ἀξόνων would probably entail that the sockets are part of the axles, which is not true.

It is worth wondering whether the word σημείοις is a later addition. It could have been added by a scribe seeking to elucidate the reference to the said points. In fact, similar references largely take the form of elliptical phrases in the treatise: cf. esp. οἱ πρὸς τοῖς $\bar{\eta}$, $\bar{\theta}$ κνώδακες (X.1 [32.20-1], X.3 [34.18-19]); but cf. VIII.1 [28.9] (τὸ $\bar{\delta}$ σημεῖον).

VII.3 [28.1-2] καὶ... εἰρημένοις. Presumably, a reference to the drive mechanism as described at V.4-5 [22.9-20].

VIII.1 [28.4-6] Ἐὰν γὰρ... ἀκίνητος. If we accept the reading γράψει supported by the best manuscripts, it seems better to accept also Schmidt's proposed emendation of μένει to μενεῖ, with only a slight change of accent. It is curious that the Teubner editor preferred γράψει over γράφει, not least because in his app. crit. he made reference to VIII.2 [28.11] (γράφουσι).

H. Schöne inserted <ἰσοσκελῆς> after κῶνος. This is unnecessary, as Hero's words seem intended to apply generally. It is not entirely clear why H. Schöne did not also suggest supplementing the text at VIII.1 [28.7-8] (οἱ δὲ $\bar{\epsilon\zeta}$, $\bar{\theta\kappa}$, $\bar{\pi\rho}$ τροχοὶ ἐν κῶνοις εἰσὶ). He perhaps realised that the cones are specified as being isosceles at VIII.2 [28.10] (οἱ κῶνοι οἱ ἰσοσκελεῖς).

For the use of the term πλευρά to denote the generatrix of a cone (or cylinder), that is, any line extending from its vertex to its base, cf. LSJ s.v. III.d (Archimedes); Mugler, *Dictionnaire* s.v.

VIII.2 [28.12] **κείμενος... ἐπιπέδῳ**. It seems necessary to add <κῶνος> here (cf. VIII.1 [28.4]), since the subject changes from plural to singular; cf. also VIII.2 [28.16] (αὐτοῦ). In his app. crit. Schmidt suggested doubtfully that the text should read either ἐν τῷ <παρὰ τὸν ὀρίζοντα> ἐπιπέδῳ or ἐν τῷ ἐπιπέδῳ <παράλληλῳ τῷ ὀρίζοντι>, adducing in support of his proposal several passages from Hero's *Dioptra* and Pappus' *Mathematical Collection* (τὸ παρὰ τὸν ὀρίζοντα ἐπίπεδον: Hero, *Dioptr.* 232.15-16, Papp. 1028.12 and 1054.5; ἐπίπεδον παράλληλον τῷ ὀρίζοντι: Hero, *Dioptr.* 204.28, 226.20-228.1, 228.12, 230.14, 230.22-3 and 232.2-3). These expressions merely serve to indicate that the plane in question, being parallel to the horizon, is horizontal (contrast ἐπίπεδος ὀρθὸς πρὸς τὸν ὀρίζοντα, denoting verticality, as in the following sentence). Such specification would be superfluous in the present context, given that Hero has already provided details on the inclination of the ground at II.1 [6.9].

VIII.2 [28.12-13] **βεβηκὼς... πλευρὰν**. The perfect participle of βαίνω is used in a strictly geometrical sense to mean 'stand' (LSJ s.v. A.1.2.b; Mugler, *Dictionnaire* s.v.). In this sense the verb is more commonly followed by ἐπί + genitive or πρὸς + dative; but for comparable examples with κατά, cf. Bito 50.10 and Ptol. *Alm.* 1.8 = 30.11-12 Heiberg. Murphy's 'moving along' (18) and McCourt's (2012: 191) 'moving upon' are clearly inappropriate; cf. also LSJ s.v. A.1.2.a.

VIII.2 [28.13-15] **τέμνεται... δίχα**. This simply means that the cone is notionally divided into two equal parts by a vertical plane passing through one of the sides of the cone, presumably along its axis. There was no need for Hero to specify which side he referred to, because in an isosceles cone (following Archimedes' terminology) all sides are equal (Heath 1897: clxv; Netz 2004b: 60 n. 63, on Archim. *Sph. Cyl.* 1.8 = 23.13-24.2 Mugler). The implication here seems to be that the weight is equally distributed between the two parts, and hence the cone remains in equilibrium. McCourt (2012: 191) understood Hero's words in a rather idiosyncratic way: 'for it is cut through by a plane perpendicular to the line produced by the side, dividing [the cone] in two'. The first observation to make is that 'the line' is nowhere to be found in the Greek text. The term πλευρά already denotes the generating line (or generatrix) of the cone (cf. note on VIII.1

[28.4-6]). Therefore, it does not make sense to say that a line is produced by the side. A second point is that ὀρθοῦ cannot govern the participle ἐκβαλλομένου. The plane resulting from the imaginary extension of the side of the cone is perpendicular to (πρός) the underlying surface (thus Schmidt 365, followed by Murphy 18), insofar as the latter is parallel to the horizon (cf. note on VIII.2 [28.12]). Finally, τὸν ὀρίζοντα is a substantive participle, and should not be taken with the following adverb (note the hyperbaton between τέμνεται and δίχα).

ἐκβαλλομένου is replaced by ἐμβαλλομένου in **M**. The latter reading ('put in[to]') does not make sense in the context of the geometrical abstraction. For ἐκβαλλομένου... ὀρίζοντα, cf. *Dioptr.* 232.12-13.

VIII.2 [28.16-18] ἕκαστον... ἡμικυκλίου. I find Schmidt's tentative suggestion that ἴση should be emended to κινούση somewhat peculiar. The emphasis is correctly placed on the uniform transmission of the force, which results in smooth, uninterrupted motion. δύναμις can be nothing else than the 'motive force'.

VIII.3 [28.20-1] ἐπινοουμένων... κορυφῆς. Brinkmann was right in suspecting the second τῶν. If we were to retain the article, we would translate thus: 'If the semicircles which <reach> up to the vertex are conceived [sc. as existing], etc.'. The main objection to the transmitted text is that the semicircles have already been imagined into existence, albeit implicitly, at VIII.2 [28.16-18]. What matters here, instead, is that the semicircles are visualised (ἐπινοουμένων) up to the vertex of the cone, and this is possible only if we delete τῶν. The presence of the article has been strangely overlooked by previous translators.

VIII.3 [28.21-2] οὐ λείπεται... διαστατόν. Because the vertex of the cone is a point (VIII.1 [28.9]; cf. *Deff.* 85), and this is, by definition, πέρας ἀδιάστατον... ἀμερές τε καὶ ἀμέγεθες τυγχάνον (*Deff.* 1). For the Neopythagorean and Neoplatonic influences on Hero's conception of geometric point, see Giardina (2003: 255-64).

VIII.3 [28.23] τοῦ... μέρη. Technically, nothing lies on the opposite side, given the adimensionality of the vertex. But Hero probably thinks about the cone in

more concrete and physical terms. **G** transmits κινουμένου instead of κειμένου. Such a reading may easily be dismissed as erroneous, because no movement at all is produced in the vertex (VIII.1 [28.6]).

VIII.3 [30.1-2] εἰ μὴ ἄρα... γίνεται. The term προωσμός, formed from the verb προωθέω ('push forward'), is a *hapax legomenon*. Manuscripts such as **G** and **M** have in its stead the meaningless reading προωρισμόν, (mis)corrected by the second hand of **M** *supra lineam* to προορισμόν ('early determination', LSJ s.v.). Baldi 22^v gave a curious paraphrase of these words: 'se non forse se [sc. la forza movente] lo [i.e il vertice] spingesse in qualche luogo stabilito'. This cannot be right, because it contradicts what has just been said. What is especially noteworthy, however, is that Baldi translated the reading in his exemplar (presumably προωρισμόν) as 'qualche luogo stabilito'. He would seem to have corrected προωρισμόν to προωρισμένον ('predetermined') and to have understood his correction as referring to an unexpressed τόπον (which is strange enough), perhaps influenced by the use of the perfect participle of ὀρίζω at I.2 [2.11] (κατά τινος ὀρισμένους... τόπους) and IV.1 [18.3-4] (ἐπὶ τινι ὀρισμένον τόπον). This, together with the fact that he took αὐτῆς as a subjective rather than as an objective genitive, meant that he had to supply 'lo' as a direct object.

IX-X [30.3-34.24] Rectangular motion

*Hero introduces a mechanism comprising two sets of three wheels, one of which is alternately raised and lowered (IX.1-3). He interrupts his description to give a fuller account of how the automaton initiates its motion (IX.4-6; cf. II.9). He then returns to the original topic to consider more closely the mechanism for raising and lowering the additional set of wheels (X, with a reconfiguration). In order to produce a rectangular pattern, the two sets of wheels will have been mounted at right angles to each other, as shown in **Figs. 8a-b** (see also Olivieri 1901: 427; McCourt 2012: 193). There is, however, at least one significant problem with this configuration: the force caused by the counterweight (no matter how heavy) would not have been enough to lower the second set of wheels and to lift the automaton (McCourt 2012: 193).*

IX.1 [30.7-8] δι' ὧν... προέγγραπται. Hero's point is not that the automaton can be carried both forward and backward along a rectangular path, but rather that the wheels $\overline{\eta\theta}$, $\overline{\kappa\lambda}$ and $\overline{\mu\nu}$ correspond to those appearing in the mechanism for forward and backward motion. Having the automaton travel backwards along a rectangle would have required programming both sets of wheels.

IX.1 [30.8-9] ἔστω δὲ καὶ... $\overline{\upsilon\phi}$. A few words must have dropped out between ὁμοίως and τὸν $\overline{\upsilon\phi}$, because the wheel $\overline{\upsilon\phi}$ (cf. IX.2 [30.13]) cannot be fitted to the same axle as the wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$. All manuscript diagrams agree in showing the wheel $\overline{\upsilon\phi}$ as being mounted on its axle within a frame that is attached to the middle of the side $\overline{\alpha\delta}$, as shown by the example of **A** (Fig. 8a). Furthermore, at X.2 [34.6-7] the wheel $\overline{\varepsilon\zeta}$ (corresponding to $\overline{\upsilon\phi}$ here) is said to be provided with its own axle $\overline{\xi\omicron}$ (not to be confused with the current axle $\overline{\xi\omicron}$). It is curious that modern scholars such as Schmidt 366-7, Murphy 18 and McCourt (2012: 193), while acknowledging that the setting of $\overline{\upsilon\phi}$ should be independent of the setting of $\overline{\pi\rho}$ and $\overline{\sigma\tau}$ (Schmidt 366 Fig. 88; Murphy 18 Fig. 4 and 41 n. 16; McCourt 2012: 194 Fig. 4), accepted the transmitted text. McCourt (2012: 193) went even as far as to say that both the axle of $\overline{\pi\rho}$ and $\overline{\sigma\tau}$ and the wheel $\overline{\upsilon\phi}$ were intended to be set within their own 'frames' (the κανόνια of X.1 [34.1]? On this term, see note on X.1 [32.22-34.1]), a fact that is not reflected in his Fig. 4 (where only the wheels $\overline{\mu\nu}$ and $\overline{\upsilon\phi}$ are correctly shown enclosed in separate casings). No less ambiguous is Schmidt, who (app. crit. ad loc.), although somewhat anticipated by Baldi 23^r ('Siavi anco la ruota u, x'), tentatively proposed reading ὁμοίως <τρίτος τροχὸς> ὁ $\overline{\upsilon\phi}$. This proposal seems to be based on a comparison with IX.1 [30.6-7] ὁ δὲ τρίτος τροχὸς ἔστω ὁ $\overline{\mu\nu}$. However, the presence of the words καὶ ὁμοίως, along with the accusative article before $\overline{\upsilon\phi}$, suggests to me that the lacuna should contain a reference to the wheel's axle (cf. ἄξων... $\overline{\sigma\tau}$). Since the axle of $\overline{\upsilon\phi}$ is not mentioned in the rest of the chapter, and indeed it is assigned its own label at X.2 [34.7], we would expect only a generic mention of it. I therefore believe that the text should be supplemented by something like <ἄξων συμφυῇ ἔχων τροχὸν> or <ἄξων ἔχων συμφυῇ τροχὸν>. The overall distribution of the adjective συμφυής (in the accusative case, serving as the predicate of an object) and the participle of ἔχω in the Heronian corpus shows a preference for the sequence 'participle + adjective' over the sequence

‘adjective + participle’: 10 instances as against 4 instances. If we confine our attention to contiguous or nearly contiguous sequences (i.e. with or without one intervening word), we find that this preference becomes less marked, with the former sequence occurring 5 times (XI.2 [36.8], *Dioptr.* 294.17, 294.22, 310.2-3, *Spir.* 164.4), and the latter 4 times (here, as well as at IX.1 [30.5-6], XI.9 [40.12], *Dioptr.* 294.1). Given that almost all (quasi-)contiguous sequences of the type ‘participle + adjective’ have the singular form of the adjective (the opposite being true of the sequence ‘adjective + participle’), the missing words are perhaps more likely to be <ἄζων ἔχων συμφυῇ τροχὸν> (cf. esp. XI.2 [36.7-8] ὁ μὲν ἦθ [sc. ἄζων]... ἔχων συμφυῇ τροχὸν τὸν κλ). Yet the context suggests otherwise. In the absence of firmer evidence, it seems more prudent to place an unfilled lacuna in the text, leaving it to the reader to decide which, if any, of these suggestions would fit best.

IX.2 [30.12-13] ὥς ἐξῆς ἐροῦμεν. Cf. X.1-3 [32.19-4.19].

IX.3 [30.17-20] καὶ ἀνασπασθέντος... πλινθίων. At some point in the transmission of the text the main clause δι’ αὐτῶν... πλινθίων was quite certainly understood as a continuation of the consecutive clause ὥστε... ἐδάφει. This meant that an early scribe added καί (deleted by Brinkmann) at the beginning of the main clause and altered πορευθήσεται (restituted by Schmidt) into the infinitive πορευθῆναι. Schmidt in his app. crit. correctly cited in support of his correction VI.1 [24.5-6] (τὸ πλινθίων πορευθήσεται) and IX.3 [30.22] (ἐνεχθήσεται τὸ πλινθίων); but, more generally, note that the future tense is used consistently throughout IX.2-5 [30.15-2.12].

IX.3 [30.23-4] ἐλεύσεται... πλινθίων. It is unnecessary to emend τὸ παραλληλόγραμμον to τοῦ παραλληλογράμμου, as doubtfully suggested by Schmidt in his app. crit. Despite the fact that ἐπί + genitive is found in a similar context (VII.1 [26.6] ἐπὶ κύκλου πορεία γίνεται, adduced by Schmidt to support his suggestion), the accusative may have been selected to convey a spatial sense of direction (LSJ s.v. ἐπί C.I.3; cf. Netz 2004a: 101 [geometrical usage]). We cannot exclude the possibility that the two constructions are used interchange-

ably: compare the occurrence of the accusative in place of the genitive at II.7 [10.18] ἐπὶ τὸ ἔδαφος (see note ad loc.).

IX.4 [32.1-2] πορείας δὲ... χαλασμάτων. Vindob. suppl. gr. 21 is the only manuscript to transmit the reading μονὰς, already conjectured by Haase and also presupposed by Baldi 23^r ('Il fermarsi'). Several other manuscripts, including **a**, have μόνας (for the confusion between the feminine form of μόνος and the term μονή, see Kroll's app. crit. to Procl. in *R.* II 188.23), which appears to have been corrupted into μόνον in some witnesses (**Ab, Bb, La, Lc, Ld**). If we were to follow Thévenot 251 and Murphy 19 in adopting the best attested reading, we would have to take πορείας as accusative plural rather than as genitive singular. This would appear somewhat strange, since Hero never uses the term πορεία in the plural. It is also not clear what purpose the cord slackenings would serve. Similar problems would arise if we tried to make sense of the variant reading μόνον: 'It [i.e. the case] will only make journeys however we choose, etc.'.

Brinkmann believed that the words τε... καὶ should be deleted, probably on the grounds that absence of motion is generally linked directly with the slackenings of the cord (cf. note on II.10 [12.19-14.3]), and not with its windings. This is true as far as it goes, but it fails to take into account the observation (XI.6 [38.8-12]; cf. XI.6 [38.12-14]) that, in order to determine the length both of the windings and of the slack hanks of cord, the automata-maker drives the case backwards by hand and starts making the windings from the point where he wants it to stop. The reason for this is that the automaton ceases to move as soon as the winding of the cord is completely unrolled, at which point the slackening starts being taken up. There is nothing suspicious, therefore, in the fact that the slackenings are mentioned alongside the windings (cf. also X.3 [34.15-16] and XI.5 [38.4-5]).

IX.5 [32.8-9] δ κλειθρίῳ... σπάρτῳ. Before the word σπάρτῳ the manuscripts have either ἐκδεθὲν (as in **AGT**) or ἐνδεθὲν (as in **M**). Schmidt (quite unnecessarily, in my view) obelised the oldest attested reading, relegating his own suggestions (ἐκδεθέντι and ἐνδεθέντι, the former being substantially anticipated by Brinkmann's ἐκδεθέντι <ἐν>), to the app. crit. Although syntactically possible, a neuter participle agreeing with the subject (ὃ) poses problems, because it is not

the hole, but the lock that is connected to the cord (cf. IX.5 [32.11-12]; cf. also XIX.4 [62.11-12]). In their translations, Baldi 23^v and Schmidt 369 included the last two words in a new sentence, which rather suggests that the main verb is missing and that the neuter nominative singular participle agrees with an unexpressed κλειθρίον: ‘detto serraglio sarà raccomandato ad una corda’ (Baldi), ‘[d]ieser [sc. Schieber] ist an eine Schnur geknüpft’ (Schmidt). This, however, entails punctuating heavily after κλεισθήσεται and, possibly, assuming a lacuna between either of the participles and σπάρτω. I prefer to adopt Schmidt’s doubtful emendation ἐνδεθέντι (apparently also adopted by Murphy 19), which makes the participle agree with κλειθρίω and avoids the need for further emendation. To support his conjecture, Schmidt cited *Spir.* 188.6 (τὸ ἄλυσείδιον τὸ ἐνδεδεμένον), but there the verb is followed by εἰς + accusative. This is the only occurrence of ἐνδέω in Hero (unless one follows Schmidt 1900: 258 and accepts the manuscript reading ἐνδεδεμένα of *Dioptr.* 308.12-13 [ἐκδεδεμένα H. Schöne, also tentatively favoured by Schmidt, but without attribution: see his app. crit. to *Mech. Frag.* 1.1 = 258.13]), although the verb is commonly attested with the dative (LSJ s.v.; cf. also, for instance, [Apollod.] *Poliorc.* 164.2-3, 173.3-4, Bito 50.6-7, 50.10-11). By contrast, the verb ἐκδέω (which occurs more frequently in Hero, especially in reference to cords) is normally construed with the genitive (with or without ἐκ, cf. LSJ s.v.); Hero uses it not only with ἐκ + genitive (e.g. XVIII.1 [58.15], XIX.4 [62.14], XXIII.8 [78.17-18]) but also with εἰς + accusative (e.g. XXIV.4 [82.13-14], XXVIII.7 [104.7-8]). Schmidt’s suggested alternative (ἐκδεθέντι) would therefore require further emendation, perhaps something along the lines of ἐκδεθέντι <ἐκ τινος> σπάρτου or ἐκδεθέντι <εἰς τινα> σπάρτον (Brinkmann’s conjecture can be easily dismissed because ἐκδέω is never followed by ἐν + dative).

The term κλειθρίον occurs only in the *Automata* and nowhere else. The term is mainly used to refer to the lock mechanism of the σύριγξ (or to either of the two mechanisms in the context of the two-counterweight configuration: XIX.3 [62.3-4], XIX.4 [62.12] and [62.15], XIX.5 [62.18-19]), but it also refers to the mechanism whereby the balls producing the sound of kettledrums and cymbals are released (XIV.1 [50.21], XIV.2 [52.6]). An entirely similar mechanism is presumably alluded to at XX.4 [66.10-13] (cf. XX.4 [66.15-16]), where Hero sets out to illustrate the device for generating the sound of thunder. In its most

basic form, the mechanism appears to consist of a slide (Prou 163; Schmidt 369 and *passim*) that is pulled back (either manually or automatically; cf. the use of the verb ἐπισπάω at XIX.4 [62.11], [62.15] and XIX.5 [62.18]; cf. also XIX.2 [62.2] and XIX.3 [62.3]) by means of a cord. In one case, there is reason to believe that the slide was closed automatically (cf. XIX.4 [62.14-15] with note ad loc.). The closest parallel to the usage of κλειθρίον is found in Str. 17.1.37, where the plural form κλειθρα denotes the locks used to regulate the inflow and outflow of water in a canal (i.e. a locking system consisting essentially of a key and a horizontally sliding wooden bar: see Bonneau 1993: 74-5 with n. 620, cited by Laudenbach 2015: 213); this use is not recorded by LSJ s.v., but see Hellmann (1992: 221 n. 18), where Strabo's passage is erroneously cited as 17.4.35. Another related meaning of κλειθρον is 'boom (harbour barrier)': cf. LSJ s.v. I.2 and, most recently, Whitehead (2016: 313), on Ph. *Parasc.* 94.40-2.

IX.5 [32.11-12] ἐπιλαμβανόμενοι... κλειθρίον. The negative οὐ is clearly a later addition, since Hero's audience is not supposed to know how the automaton is activated (in his app. crit. Schmidt misreported that manuscripts **Lb** and **Pc** omit οὐ, and therefore left it out from the text: see Schmidt, *Supplementum* 114 and 115 n. 1). The reading might have arisen from a copyist repeating the ending of the preceding σπάρτου.

IX.5 [32.12-13] καὶ οὕτως... πλινθίον. The passive form κινεῖται (**La**^{mg}; cf. 'si faccia il moto', Baldi 23^v) is to be preferred to the active form κινεῖ (transmitted by all other manuscripts, including Leid. Bon. Vulc. 4 *in textu*) because τὸ πλινθίον is best understood as subject (Baldi 23^v; Couture 251; Murphy 19) rather than as object ('setzt die Schnur den Radkasten in Bewegung', Schmidt 369). The reading κινεῖ would necessitate a pronominal subject referring to the pouring out of millet (e.g. <τοῦτο> κινεῖ τὸ πλινθίον). Contrast IX.6 [32.15-17] ἢ σπάρτος... ταθεῖσα κινήσει τὸ πλινθίον. Schmidt expressed his tentative approval of κινεῖται by citing X.3 [34.17] (κινεῖται τὸ πλινθίον); for the passive of κινέω, cf. also I.2 [2.12], II.3 [8.4] and VIII.2 [28.19].

Murphy 19 seems to have understood the term βάσις here as referring to a catch basin placed somewhere inside the base of the automaton. I fail to understand why the term should denote anything different from the base containing

the wheels (cf. note on II.7 [10.18-19]), primarily because it has been used consistently up to this point. It is not difficult to imagine the millet pouring out on the ground, if we suppose that the base was bottomless. The bottom of the case had to be at least partially hollow to allow the wheels to rest on the ground.

On Hero's use of ἡρέμα, see note on II.9 [12.10-13].

IX.6 [32.15-17] ἔξει... πλινθίων. It is tempting to emend κινήσει to κινήση, since Hero almost always uses the subjunctive after ὅπως. Cf. esp. IX.5 [32.9-12] and, for a similarly constructed passage, XVI.3 [56.6-8]. There are, however, at least two other instances of ὅπως with future indicative: XXVI.8 [96.3-5] περιτίθημι ἄξονα... ὅπως... στραφήσεται, *Geom.* 414.28-416.1 Εὐρεῖν δύο χωρία... ὅπως τὸ τοῦ πρώτου ἐμβαδὸν... ἔσται τριπλάσιον (with a seemingly paratactic construction used imperatively; on this usage, cf. Cooper 1998: 720-22).

X.1 [32.19-20] ἑστῶσαν... ἡθ. The wheels $\overline{\alpha\beta}$, $\overline{\gamma\delta}$ and $\overline{\epsilon\zeta}$ correspond, respectively, to $\overline{\pi\rho}$, $\overline{\sigma\tau}$ and $\overline{\upsilon\phi}$, as illustrated in **Fig. 8a**. The axle $\overline{\eta\theta}$ corresponds instead to $\overline{\xi\omicron}$ (cf. IX.1 [30.8-9] and Schmidt 369 n. 1). The manuscript diagram accompanying this (re-)configuration lacks any letter labels, but these were first supplied by Thévenot 252 unnumbered Fig.; see also Baldi 24^r unnumbered Fig., but with partial lettering.

X.1 [32.22-34.1] τὰ οὖν... κανόνια. No explanation is given of what these κανόνια are. Baldi 23^v ('rigoli') and Couture 251 ('normulis') strangely understood the term as indicating 'rulers' or 'measuring-rods' (LSJ, *Supplement* s.v. κανόνιον); similarly, but more generally, Schmidt 371 ('Latten'). The term is used elsewhere in the treatise in its general sense (X.2 [34.9], on which see more below; ὑσπλήγγιον: XXIV.3 [82.8], [82.10], [82.11] and XXIV.4 [82.13]), but here it seems to have a more specific meaning. The observation that the wheel $\overline{\epsilon\zeta}$ is placed ἐν τινι κανονίῳ (X.2 [34.3]; on such arrangement, cf. note on X.2 [34.3-5]), in fact, points to some kind of frame. This is not entirely surprising, considering that the semantically related diminutive κανονίς is attested in the meaning of 'door-frame' (Hellmann 1992: 187 with n. 7): *IG* 2².1672.155 (Eleusis, 329/328 BCE; but LSJ, *Supplement* s.v. II doubtfully suggest 'upright of a door-frame'), *ID* 1403 Bb col. I 48 (165–157/156 BCE). Add to this that Hero,

Bel. 100.8-9 uses the base noun κανών to refer to the beams constituting the stock of a stone-throwing engine, the so-called κλιμακίς ('ladder'; on this, see Marsden 1969: 23-4 with Fig. 13): **διάπηγμα** κατασκευάζεται ἐκ τεσσάρων κανόνων συνεστηκός. For a similar use of the derivative κανόνιον, cf. *Ph. Bel.* 74.7-8.

Murphy 19 first adopted the term 'bar-frame' (which I also adopt in my translation) to refer to the κανόνιον of wheel $\overline{\epsilon\zeta}$ (in addition to the above-cited occurrence, cf. X.2 [34.5], [34.7] and X.3 [34.13]; cf. also Murphy 41 n. 17), but rendered the other occurrences of the word by either 'bars' (here and X.1 [34.1]) or 'guide-bars' (X.2 [34.9]). Although the wheels $\overline{\alpha\beta}$ and $\overline{\gamma\delta}$ (unlike $\overline{\epsilon\zeta}$) are not each encased by their own κανόνιον (they are in fact on the same axle; an arrangement similar to that of $\overline{\epsilon\zeta}$ would have required $\overline{\alpha\beta}$ and $\overline{\gamma\delta}$ to be mounted on separate axles), there seems to be no reason why the term should be taken as denoting a different structure. The three κανόνια are all attached to the sides of the case with dovetails (cf. X.1-2 [34.1-4], and following note), their purpose being to permit simultaneous lifting and lowering of the wheels (cf. X.3-4 [34.17-23]). The case is different with regard to X.2 [34.9], where the term seems merely intended to specify the shape of the γόμφοι, 'dowels' (see further note on X.2 [34.9]). I cannot understand why the γόμφοι should serve as 'guide-bars' (my emphasis). They appear to be used only to hold the screw $\overline{\phi\chi}$ in place, allowing it to rotate but not to slide back and forth: cf. X.2 [34.10-11].

Schmidt tentatively suggested adding either <ἐνηρμοσμένα> or <ἐμβεβηκότα> between ἔστω and εἰς. Neither of these supplements accords with the nature of the ἐμπυελίδια. The constructions ἐναρμόζω + εἰς and ἐμβαίνω + εἰς, as used by Hero, refer to components fitting one into the other: for example, pivots into sockets (ἐμβαίνω: II.3 [8.6]; ἐναρμόζω: X.1 [32.21], adduced by Schmidt in support of <ἐνηρμοσμένα>). The sockets, which are made to receive the pivots, are to be fitted on(to) the κανόνια, not 'into' them (as with Murphy 19), just as at XI.9 [40.9-10] other ἐμπυελίδια are on (ἐν) either side of a διάπηγμα (cf. also V.3 [20.20-1] πυελίδας... ἐν τοῖς... τοίχοις, with Keenan-Jones-Ruffell-McGookin 2016: 176). The preposition εἰς is here clearly used instead of ἐν, a late usage (LSJ s.v. εἰς I.2; cf. XXVII.2 [98.11] and *Spir.* 16.4 and 274.4, with Hammer-Jensen 1910: 502).

X.1 [34.1-2] τὰ δὲ κανόνια... τοίχους. Sliding dovetail joints are probably used here because the κανόνια are joined perpendicularly (ὀρθά, cf. X.2 [34.3]) to the sides of the case. In order for the κανόνια to be able to move up and down (X.3 [34.12-13]), the joints will not have been made too tight. The term πελεκίνος in its technical sense of 'dovetail' (LSJ s.v. III) has been convincingly explained by Orlandos (1968: 102) as referring to the double-axe shape of the joint (cf. Lat. *securic[u]la*, OLD s.v. 2); see also Baldi 44^r n. 21 and, more recently, Ginouvès-Martin (1985: 109).

X.2 [34.3-5] τὸ ἐξ... πλινθίου. The details of this arrangement have been discussed by Murphy 41 n. 17, who envisaged three possibilities: (1) the wheel is set so as to protrude through the side of the case; (2) the κανόνιον has a width greater than the radius of the wheel, and hence it serves as a frame for the wheel; (3) the κανόνιον holds the wheel by means of a projecting bracket (as shown in Schmidt 371 Fig. 90a). The idea that the wheel is entirely or partly encased by the κανόνιον as if by a frame (cf. note on X.1 [32.22-34.1]) must be closer to the truth than the other two possibilities, as also suggested by the manuscript diagrams. As can be seen in **Fig. 9**, the wheel on the right-hand side, unlike the remaining wheels, is placed into what appears to be its κανόνιον (compare with **Fig. 8a**; see note on IX.1 [30.8-9]). This very arrangement is also reproduced in perspective in Baldi 24^r unnumbered Fig. As for the first possibility, it is not clear to me why the wheel should stick out through the side. This, or a similar arrangement, would involve dislocating the wheel, which is neither described nor implied anywhere in the text. There is, in any case, an inconsistency between Murphy's claim (41 n. 17) that the κανόνιον moves in a dovetail on the side of the case (as illustrated in Murphy 20 Fig. 5) and her interpretation of the words τὸν πρὸς τῷ ἐξ τοίχον τοῦ πλινθίου ('the side of the base *facing* EZ' [19], my emphasis; same understanding at X.2 [34.8-9]). Πρὸς is here followed by the dative, not by the accusative, and clearly indicates proximity (LSJ s.v. B.1), as at VII.3 [26.20] (mathematical usage: Mugler 1958: 26); cf. also X.1 [32.22].

Schmidt's καταβιβαζομένῳ (καταβιβαζομένου codd.) is no doubt correct. Cf. X.1 [34.1-2] τὰ δὲ κανόνια διὰ πελεκίνων καταβαίνεται. Note the *variatio* between the verbs καταβαίνω and καταβιβάζω.

X.2 [34.5-6] ἔστω... κ̄λμν. Schmidt's correction of the manuscript reading η̄θ (cf. also X.3 [34.13]) is not trivial because η̄θ already denotes the axle of the main wheels (Schmidt 371 n. 1): X.1 [32.19-20]. Manuscript **Ad** alone transmits the nonsensical κ̄θ (an error owing to confusion between η and κ). The letter κ̄ designates one corner of the mortise κ̄λμν and cannot be conjoined with θ.

X.2 [34.8] ἐνειλείσθω. LSJ s.v. ἐνειλέω do not record this sense of 'screw on', 'joint', attested only here and at X.2 [34.9]; cf. *DGE* s.v. A.II.2. This specialised meaning presumably developed from the basic passive meaning of 'to be enwrapped' (LSJ s.v. I; cf. also *DGE* s.v. A.I.1).

Pa transmits ἐνείσθω. This erroneous reading must have arisen from the omission of the penultimate syllable of ἐνειλείσθω. The verb ἐνίημι (which, in its basic sense, means 'send in[to]', LSJ s.v. 1) does not fit well within the context of the sentence. The only occurrence of the form ἐνείσθω in Greek literature is Hp. *Aff. Int.* 48 = 7.288.9 Littré ἐσθῆτα δὲ ἐνείσθω [*sc.* ὁ νοσέων], but there the verb is used in a middle rather than a passive sense.

X.2 [34.9] δύο γόμφοι καθάπερ κανόνια. This comparison comes as a surprise, because the term κανόνιον occurs throughout the chapter in reference to the bar-frames which make it possible to raise and lower the wheels. It seems to me, though, that κανόνια here should be understood in a more general sense as 'bars' – Murphy 19 goes astray in her rendering 'guide-bars'; cf. note on X.1 [32.22-34.1]. The reason for this is that the noun γόμφος can indicate any small object used to fasten components together, as transpires from a Cyrillian gloss in Hesychius: Hsch. γ 805 Latte γόμφοι· μύλοι. σφήνες. δεσμά. ἄρθρα. σύνδεσμοι. καὶ ὀδόντες γόμφοι. The Hesychian gloss on the term is even more vague, although it only concerns woodwork (Hellmann 1992: 85 n. 4): Hsch. γ 806 Latte γόμφοις· ταῖς τῶν ξύλων ἀρμογαῖς. Such terminological polyvalence led to different translations: 'chiodi' (Baldi 23^v), 'cuneoli' (Couture 252), 'Bolzen' (Schmidt 373). Among these, the most curious is that of Baldi. The term, in fact, does not ever seem to refer to a nail (cf. LSJ s.v. and Hellmann 1992: 84-6), despite Hsch. γ 808 Latte γομφωτήρια· ἦλοι (for γομφωτήριον in the sense of 'tenon', cf. XXVII.1 [98.5]). The Renaissance scholar, however, apparently understood that Hero adduced the comparison to clarify his reference to the two

γόμενοι – a procedure followed elsewhere in the text: II.6 [10.6-8], XII.2 [42.16-17], XXVII.1 [98.5], XXVIII.3 [100.18-19]; cf. XIII.9 [50.10-11] and XX.4 [66.17-18]; XXVIII.4 [102.10-11] (ὅπῃ διαφαίνουσα ὥσεί θυρίς) almost certainly represents a stylistic mannerism. Baldi's understanding of the comparison (later endorsed by Couture and Schmidt) largely hinged on his understanding of the word κανόνιον (cf. note on X.1 [32.22-34.1]): 'chiodi *piani* come rigoli' (my emphasis). This interpretation has two disadvantages. First, it does not take into account the γόμενοι's function as supports for the screw (cf. X.2 [34.10]). If they were used to hold the screw, they were probably not too flat. Second, it rests on an erroneous interpretation of the word κανόνιον, which often denotes simply anything bar-shaped (in Hero, too: LSJ s.v. I; for further references in Hero's *Belopoeica*, see, for example, *Bel.* 77.3, 77.5, 78.2). Given the semantic indeterminacy of the term γόμενος, the most natural assumption is that Hero adduced the comparison καθάπερ κανόνια to specify the shape of the fastening elements rather than their thickness. If this is the case, then we have to understand γόμενοι as 'dowels' or 'pins' (Ginouvé-Martin 1985: 112), dismissing other possible shapes such as wedges (σφήνες/*cuneoli*) or tenons.

X.3 [34.16] διαμεμηρυμένα. LSJ s.v. διαμηρύω cite the present occurrence as the only attestation of the verb διαμηρύομαι (erroneously recorded as active). The verb occurs three more times (XI.11 [42.6], XVI.3 [56.7], *Bel.* 108.9), or five more times if one counts the two occurrences in the fragments preserved by Pappus: *Mech. Frag.* 2.1 and 3.1= Papp. 1118.8-9 (deleted by Hultsch) and 1132.9 (middle). In most instances, the verb refers to the act of winding a cord (or its slackenings) into hanks. On one occasion (*Bel.* 108.9), Hero uses the verb to describe the process of threading the spring-cord through holes in the frame of a catapult.

X.3 [34.16-17] ἄρμοστὰ... πλινθίων. Note the *variatio* with XI.5 [38.5-6].

For the technical use of ἄρμοστός, cf. *DGE* s.v. I.1, citing the present passage and XVI.1 [54.14] among others.

X.4 [34.20-2] **δεῖ δὲ τοὺς... ὁμοίως.** A rare piece of advice intended for the expert builder. For a statement of (allegedly) exact proportionality, cf. XXIII.1 [74.7-9].

XI [36.1-42.8] Other forms of motion

Hero now discusses three different configurations for snake-like motion, with only passing mention of the possibility of making the automaton travel along non-rectangular polygonal paths (XI.1). At their basic level, all three mechanisms share the idea of a differential drive to produce changes in direction. The first mechanism (XI.2-5) has the two front wheels independently mounted on hubs, and the rear (non-driving) wheel turning on pivots. The second mechanism (XI.7) is a modified – but probably unsuccessful – version of the previous configuration, featuring the addition of a third hub but with the rear axle now attached to the case and a cord connecting the hub to the counterweight. The third and last mechanism (XI.9-10), explicitly favoured for technical reasons (αἱ χοινικίδες... ἐν τῇ κινήσει δυσχερῶς ἐπιστρέφονται, XI.8), replaces the χοινικός type of bearing with the κνώδαξ, and the single front axle with two independent axles. Both XI.7 and XI.10 have been condemned by the previous editor as interpolations (Schmidt LIII-IV). The incipit βέλτιον δὲ καὶ, etc. (XI.7) alone argues against interpolation, for it occurs, in a slightly modified form, in at least two other places (II.5 and Spir. 202.9-10). The addition of the third hub does not contradict XI.8, because Hero does not express his preference for the second configuration. As regards XI.10, the idea that each axle receives two cords is clearly wrong. That Hero is employing single cords is suggested not by XI.11 (as argued by Schmidt), but by his actual use of διπλός (cf. note on XI.10 αἱ δὲ περὶ... στρέφειν). For further arguments against interpolation, see notes ad locc. Nor does it make sense to propose, as Murphy 42 n. 22 does, that, taken together, XI.7 and XI.10 describe an alternative to the first configuration. They indeed describe two different configurations with different bearings. The flow of the narrative is once again interrupted (XI.6; cf. IX.4-6) to incorporate more general information on the (empirical) measurement of cords.

XI.1 [36.1-3] **Δυνατὸν δέ... σχήματι.** Hero does not elaborate, but the incipit, a variation of OPENING E, makes it clear that he refers to an improvement of his

own devising, quite possibly one that he did not finalise. In modern terminology, a ‘rectilinear figure’ is simply a polygon: cf. Euc. 1 *Def.* 19 Σχήματα εὐθύγραμμά ἐστι τὰ ὑπὸ εὐθειῶν περιεχόμενα, etc. Cf. also Hero, *Deff.* 39, with Giardina (2003: 299-300).

XI.2 [36.7-10] ἄξονες... εἰργασμένος. Manuscript diagrams show both these axles fixed to the case (see **Fig. 11a**), even though Hero’s counterposition (ὁ μὲν $\overline{\eta\theta}$... ὁ δὲ $\overline{\epsilon\zeta}$ συναραρῶς ἔστω τῷ πλινθίῳ) suggests that $\overline{\eta\theta}$ was, in fact, intended to be detached from it. Were it not so, we could not understand the proposed change of XI.7 [38.15-17], which, indeed, must have led to modifications of the original diagram. Previous editors and translators, notably Baldi 25^r unnumbered Fig., Schmidt 374 Fig. 91a and Murphy 21 Fig. 6, have placed wheel $\overline{\kappa\lambda}$ within a frame in the middle of side $\overline{\gamma\delta}$, probably influenced by the wheel configuration for straight-line (**Figs. 4a-b**) and rectangular (**Figs. 8a-b**) motions; see also my modern reconstruction (**Fig. 11b**) and note on XI.10 [40.18-19]. Hero’s silence in this respect is not surprising, for only once does he mention the peculiar arrangement of the third, non-driving wheel: V.4 [22.5-7]; but cf. IX.1 [30.7-8] with note ad loc.

Murphy 41 n. 18 took the words ἀπὸ τόνου ἰσοπαχῆς εἰργασμένος to mean that the axle $\overline{\epsilon\zeta}$ should be made as thick as the other axle. This, however, is not implied by the Greek text. The significance of Hero’s words has to do with the necessity to reduce friction and to ensure smooth turning of the χοινικίδες around the fixed axle $\overline{\epsilon\zeta}$ (see generally Keenan-Jones–Ruffell–McGookin 2016: 177), as becomes apparent from the immediately following lines: XI.2 [36.10-13]. On Hero’s recurring insistence on the use of the lathe, cf. note on II.3 [8.4] ἔντορνά τε ἀκριβῶς.

XI.2 [36.11] εὐλύτως καὶ ἁρμοστῶς. On the pairing of these adverbs, see note on II.8 [12.6-7].

XI.2 [36.12] καὶ αὐταὶ. I prefer the reading of **Ld** (αὐταὶ, already conjectured by Schmidt on the basis of V.3 [22.2-3] καὶ αὐτή) to that of **M** (αὐται). Schmidt printed the latter reading, although it is not clear whether he took it from **M** or corrected it from **AGT** (αὐται).

XI.3 [36.17-18] **καταφερομένης... τροχούς**. These lines recall Hero's first description of the axle-wheel arrangement (II.7 [10.16-17]), but here the asyndeton between the two genitive absolutes shifts the focus from the mechanism by which motion is transmitted to the rapidity with which the individual movements succeed one another; for a similar use of asyndeton, cf. XI.7 [38.24-40.1]; see also, for instance, E. *Andr.* 1154 βάλλων ἀράσσω, with Allan (2009: 197). Murphy 20 rendered the second genitive absolute as a subordinate clause ('as the strings are unwound'), thus obscuring the causal relationship between the fall of the counterweight and the unwinding of the cords. Other translators, such as Baldi 24^v, Couture 253 and McCourt (2012: 195), correctly understood the syntax, but they all replaced the 'cords' with a single cord. Not only does this violate grammar, but it also contradicts XI.3 [36.15].

XI.5 [38.1-3] **δεήσει... ἐνεχθῆναι**. In other words, the size of the slackening is determined based on the desired length of the trajectory of the automaton. There is no mention of how the turning angle could be regulated, but that must have depended mainly, but not only, on the wheel arrangement. For a description of the method used to measure lengths of cord, cf. XI.6 [38.7-12] with note ad loc.

XI.6 [38.7-12] **δεήσει... δώσωμεν**. For the rationale behind this process, cf. note on IX.4 [32.1-2].

Berryman (2009: 142 n. 165) sees a contrast here (albeit without giving the precise reference), as elsewhere (?), between what happens automatically (τὸ αὐτόματον) and what happens by trial (ἐκ πείρας). I cannot find such a contrast anywhere in Hero's corpus. What I do find is a contrast (either explicitly or implicitly articulated) between automatic processes and manually induced (ταῖς χερσίν or τῇ χειρὶ) movements: in addition to the present passage, cf. XXIII.3 [74.18-76.1], XXVII.3-4 [98.16-20], XXX.4 [108.3-4], *Spir.* 186.9-12 and 198.12-200.1; cf. also XXIV.1 [82.5-8] (τοῖς δακτύλοις vs αὐτόματον). In fact, the phrase ἐκ πείρας or, more correctly, ἐξ αὐτῆς τῆς πείρας is not used to describe the manual steps involved in the measuring process, as argued by Berryman, but, rather, to describe a systematic testing procedure. This emerges from a comparison between Hero, *Bel.* 112.8-113.4 (εἰδέναι δὲ δεῖ ὅτι ἡ τῶν μέτρων [sc. τῶν εὐθυτόνων καὶ παλιντόνων] ἀναγραφή ἐξ αὐτῆς τῆς πείρας ἐλήφθη,

etc.) and Ph. *Bel.* 50.14-29, where Philo gives an account of the discovery of the diameter of the hole that receives the spring of the catapult as the guiding principle in artillery construction. The emphasis placed there on the importance of *πεῖρα* serves to indicate that the discovery would not have been made without systematic empirical testing (Schiefsky 2015: 628-31; cf. also Ferrari 1985: 256). Hero likewise assigns an important role to practical testing. Repeated testing enables the practitioner to determine specific measurements (here, as at *Spir.* 288.2-3 *πεῖρα οὖν εὐρόντες τὰ μέτρα*, etc.); it promotes understanding of how components fit together (*Spir.* 320.13-14 *πεῖρα οὖν σκεψόμεθα πότε μὲν κατάλληλον τὸ τρῆμα τῷ ΜΟ σωλῆνι*, etc.); it assists in calculating the speed ratio between a screw and a cogwheel (*Dioptr.* 298.6-9). Hero, however, goes further than assigning a heuristic status to *πεῖρα*. Just as importantly, testing serves as a basis for comparing the poor performance of earlier automata with the superior performance of Hero's own models: XX.1 [64.4-7] *καὶ γὰρ εὐκόπως καὶ ἀκινδύνως καὶ ξένως παρὰ τὰ πρὸ ἡμῶν ἀναγεγραμμένα κατακεχωρίκαμεν, ὥς ἔστι δῆλον τοῖς πεπειραμένοις τῶν πρότερον ἀναγεγραμμένων*; cf. V.1 [20.10-12]. That is to say, it provides the ultimate guarantee of the safety and effectiveness of the devices. It is in this light, too, that one should read Hero's concern about the potential failure of the mobile automaton: cf. II.4 [8.11-12] and, more ominously, II.11 [14.7-10].

XI.7 [38.15-19] *βέλτιον δὲ καὶ... ἀποδοθῆναι*. This configuration seems to reflect a failed attempt to improve the simpler arrangement of XI.2-5 [36.7-8.4]. While the addition of the third hub, as well as of the third cord (both deemed pointless by Schmidt LIII; cf. note on XI.10 [42.2-3]), might be explained on the basis of the designer's desire to obtain more control over the third wheel (Murphy 41 n. 20), the slackenings of the cord have no purpose (Schmidt LIII). In fact, as noted by the Teubner editor, the wheel $\overline{\kappa\lambda}$ has been presented as continuously rotating (XI.3 [36.19-20], XI.4 [36.22-3]; cf. XI.5 [38.3-4]), which is also consistent with XI.7 [38.22-40.2]. Assuming that $\overline{\kappa\lambda}$ could be forced to stop turning because of the slackening of its cord, it would still have been dragged by either or both of the two other wheels. The words *καὶ τὰ χαλάσματα ἔχουσιν* (see app. crit. ad loc.) seem therefore to have been interpolated in order to make

the arrangement of $\overline{\kappa\lambda}$ match exactly the arrangement of the main wheels $\overline{\pi\rho}$ and $\overline{\sigma\tau}$.

There is no reason to emend $\acute{\epsilon}\nu$ to $\sigma\acute{\upsilon}\nu$, as hesitantly proposed by Schmidt in his app. crit. Schmidt did not adduce any evidence in support of his conjecture, although he probably thought of XI.3 [36.18] ($\acute{\epsilon}\pi\iota\sigma\tau\acute{\rho}\epsilon\sigma\theta\alpha\iota\ \sigma\acute{\upsilon}\nu\ \tau\alpha\acute{\iota}\varsigma\ \chi\omicron\iota\nu\iota\kappa\acute{\iota}\varsigma\iota$). The verb used here, however, is not $\acute{\epsilon}\pi\iota\sigma\tau\acute{\rho}\epsilon\omega$ but $\pi\epsilon\rho\acute{\iota}\kappa\epsilon\iota\mu\alpha\iota$, which refers to the mounting of the wheel. Cf. XI.9 [40.12-14] $\acute{\epsilon}\kappa\acute{\alpha}\tau\epsilon\rho\omicron\varsigma$ [sc. $\tau\omicron\omega\nu\ \tau\rho\omicron\chi\omicron\nu$] $\kappa\epsilon\acute{\iota}\sigma\theta\omega\ldots\ \acute{\epsilon}\nu\ \kappa\nu\acute{\omega}\delta\alpha\acute{\xi}\iota\nu$.

XI.7 [38.19-23] $\dagger\acute{\omicron}\pi\omega\varsigma\dagger\ldots\ \tau\rho\omicron\chi\omicron\upsilon$. I agree with Schmidt LIII that $\acute{\omicron}\pi\omega\varsigma$ poses a serious linguistic problem, but disagree that it constitutes a strong argument for interpolation. He put a *crux* in front of it, but deemed it ‘spurium’ in his app. crit. This is somewhat curious, since he had already deleted the whole of XI.7 (see also my app. crit. to $\kappa\alpha\acute{\iota}\ \tau\grave{\alpha}\ \chi\alpha\lambda\acute{\alpha}\sigma\mu\alpha\tau\alpha\ \acute{\epsilon}\chi\omicron\upsilon\sigma\alpha\nu$). None of the proposed emendations is entirely convincing. Brinkmann suggested adding either $\langle\sigma\upsilon\mu\beta\eta\rangle$ or $\langle\pi\omicron\iota\eta\sigma\omega\mu\epsilon\nu\rangle$ after $\acute{\omicron}\pi\omega\varsigma$, but neither of these verbs is ever found as the main verb of a final $\acute{\omicron}\pi\omega\varsigma$ clause in Hero. Schmidt proposed doubtfully $\acute{\omega}\varsigma$ (= $\acute{\omega}\sigma\tau\epsilon$) in place of $\acute{\omicron}\pi\omega\varsigma$, but Hero typically uses a consecutive $\acute{\omega}\varsigma$ to introduce shorter, syntactically less convoluted clauses; for instances of this usage, see Schmidt (1899b: 180-1) s.v. $\acute{\omega}\varsigma$ (but I.1 [2.6] should be regarded as limitative) and Heiberg (1914: 273) s.v. $\acute{\omega}\varsigma$. The presence of accusative and infinitive constructions ($\acute{\epsilon}\nu\alpha\ldots\ \acute{\epsilon}\sigma\tau\acute{\alpha}\nu\alpha\iota$ and $\tau\omicron\nu\ \delta\grave{\epsilon}\ \overline{\kappa\lambda}\ \tau\rho\omicron\chi\omicron\nu\ldots\ \sigma\tau\acute{\rho}\epsilon\phi\epsilon\sigma\theta\alpha\iota$) suggests that we need a $\acute{\omega}\sigma\tau\epsilon$, but it is difficult to see how that would have been corrupted into $\acute{\omicron}\pi\omega\varsigma$. I have placed $\acute{\omicron}\pi\omega\varsigma$ between *cruc*es and translated *ad sensum* (as previous translators did), taking the infinitives $\acute{\epsilon}\sigma\tau\acute{\alpha}\nu\alpha\iota$ and $\sigma\tau\acute{\rho}\epsilon\phi\epsilon\sigma\theta\alpha\iota$ as the main verbs of the final clause.

XI.7 [38.24-40.1] $\pi\acute{\alpha}\lambda\iota\nu\ldots\ \tau\rho\omicron\chi\omicron\upsilon$. Manuscripts read the words $\acute{\alpha}\mu\alpha\ldots\ \tau\rho\omicron\chi\omicron\upsilon$ in the sequence $\acute{\alpha}\mu\alpha\ \tau\omicron\omega\nu\ \tau\rho\iota\omega\nu\ \kappa\iota\nu\omicron\upsilon\mu\acute{\epsilon}\nu\omega\nu\ \tau\rho\omicron\chi\omicron\upsilon$ (‘along with the three moving wheels’), which does not make sense in the context. More importantly, the use of the genitive with $\acute{\alpha}\mu\alpha$ is quite rare (cf. LSJ s.v. $\acute{\alpha}\mu\alpha$ B.II). When Hero uses $\acute{\alpha}\mu\alpha$ prepositionally, he always employs the usual construction with the dative: see, for example, IV.2 [18.13] and IX.6 [32.14]. Previous translators misinterpreted the transmitted sequence as a genitive absolute, without paying attention

both to the prepositional value of ἅμα and to the position of the participle κινουμένων. The transmitted text is best explained by supposing that κινουμένων has at some point been misplaced. I have therefore transposed κινουμένων and placed it after ἅμα. Because of the transposition, ἅμα now serves as an adverb modifying the genitive absolute κινουμένων... τροχῶν, and the two genitive absolutes are asyndetically connected. Cf. XI.3 [36.16-18] with note ad loc. For the sequence of movements, cf. also XI.4 [36.25-6].

XI.7 [40.2] τὴν ἐπ' εὐθείας ὁδὸν φέρεται τὸ πλινθίον. The subjunctive φέρεται depends on the preceding ἄχρις. Baldi 25^v and Couture 254 treated it as a main verb, but probably only because of the complexity and length of the sentence. Brinkmann, conversely, construed it as dependent on the preceding ὅπως, with the effect of straining the syntax (even assuming that ὅπως should govern another verb that is now missing: cf. note on XI.7 [38.19-23]).

For other examples of the phrase τὴν ὁδὸν φέρεσθαι, cf. App. BC 5.14.142 and Gal. UP 3.580 and 653 Kühn.

XI.8 [40.3-4] περικείμεναι τοῖς ἄξοσιν. These words were unnecessarily regarded by Schmidt LIII as an interpolation resulting from XI.7.

XI.8 [40.4-5] ἐν τῇ κινήσει... ἐπικεῖσθαι. For problems associated with the load-bearing capacity of the χοινικίδες, see Keenan-Jones-Ruffell-McGookin (2016: 179).

Schmidt's addition of <τὸ> is necessary, because the infinitive of ἐπικεῖμαι is used substantively (διὰ <τὸ>... ἐπικεῖσθαι). Its omission in the manuscripts can be easily explained by haplography.

XI.8 [40.6] ἀρέσκει. An idiom not used elsewhere in the text (see Introduction, pp. cxii-cxiii with n. 245).

XI.8 [40.6-7] ἐν τοῖς... στρέφεσθαι. Hero's preference for the κνώδαξ type of bearing seems to be dictated by concerns over friction (Keenan-Jones-Ruffell-McGookin 2016: 177).

XI.9 [40.8-9] **γεγονέτω... ἄραρός**. Instead of **τόπον** (a doubtful conjecture of Schmidt, anticipated by Baldi 25^v), the manuscripts have **τρόπον** (adopted by Schmidt 378 and Murphy 22; see below), which does not make sense ('in the same way as the axle, etc.'). Other supplements and emendations have been proposed. Brinkmann emended **τὸ πλινθίον** to **τῷ πλινθίῳ** (made to depend on **ἄραρός**, which is harsh), but **γεγονέτω γὰρ** demands the presence of a subject in close proximity: cf. *Spir.* 32.7 **γεγονέτω γὰρ σίφων ἔχων**, etc. Cf. also XI.10 [40.18-19] and XIII.6 [48.3-4]. Schmidt put a *crux* before **τὸ πλινθίον**, while tentatively suggesting (app. crit. ad loc.), on the basis of XXIV.5 [82.21-2] (**ἐν τῷ ἔμπροσθεν μέρει τοῦ πίνακος**), **<ἐν τῷ ἔμπροσθεν μέρει> τοῦ πλινθίου**. He also wanted either to delete **καθ' ὃν τρόπον... ἄξων** or to transpose it (reading **τόπον** for **τρόπον**) after XI.9 [40.11] **γεγονέτωσαν** (an option partly adopted in his translation, albeit with persistent doubts [379 with n. 1]: 'Man mache aber (in der Weise wie die Achse mit den zwei Rädern) zwei Achsen'). These changes seem unwarranted. First, XXIV.5 [82.21-2] provides a weak basis for emendation. Second, if we emend **τρόπον** to **τόπον** (a common enough scribal error), the words **καθ' ὃν... ἄξων**, although incomplete, no longer appear misplaced. Later in the text (XI.9 [40.12-14]), the two axles, such as can be seen in **Figs. 14a-b**, are described as being set between the **διάπηγμα** and the sides of the case. A transposition would therefore be pointless. Third, without the words **καθ' ὃν... ἄξων**, we would have no indication whatsoever of the position of the **διάπηγμα**, and it is not clear why an interpolator, and not Hero, would have thought fit to include the information. I adopt Hildebrandt's **<ἔχων>**, anticipated by Baldi 25^v ('habbia'). This supplement, which has been adopted by Schmidt 379 in his translation ('Es habe nämlich der Kasten, etc.'), has two advantages: it gives a typically Heronian construction, and it is easy to explain palaeographically (**τὸ πλινθίον <ἔχων>... ἔχων**). However, it still requires (as do all the other proposed emendations) the addition of a main verb within the relative clause **καθ' ὃν... ἄξων**. I have added **<ῆν>** after **ἄξων**, partly on the basis of a comparison with Ph. *Bel.* 75.6-7 **συνείχετο δὲ [sc. ἡ σύριγξ] πρὸς τὴν κάτω σύριγγα... καθ' ὃν τόπον ὁ ὀνίσκος ῆν**. The past tense of the verb 'to be' (already supplied by Baldi 25^v) is needed, because the single axle which appears in the previous two configurations has now been replaced by two distinct axles. This verb form probably dropped out by partial homeoteleuton (**ἔχων ἄξων <ῆν> ὀρθιον**). I do not under-

stand why the variant reading γενέσθω (**A^{pc}G**) for γεγονέτω should be ‘more logical’ (Murphy 41 n. 21). The form γενέσθω is found elsewhere in Hero only once (*Geom.* 250.20), whereas γεγονέτω occurs several times: for occurrences in the *Automata*, cf. VII.3 [28.1], X.3 [34.17], XI.10 [40.18], XIII.6 [48.3] and XIX.2 [62.1]; cf. also XI.9 [40.11], quoted above. Murphy 22 mistranslates here: ‘Let a right-angled partition be attached in the same manner as the base to the axle holding the two wheels’.

XI.9 [40.14-16] ὥστε... κνώδαζιν. These lines have been suspected by Schmidt LIII of being an interpolation. He claimed that ἕκαστον... κνώδαζιν repeats something that has already been said (he did not cite a specific passage, but he presumably had in mind XI.8 [40.6-7] ἀρέσκει... στρέφεσθαι) and that βεβηκέναι... τροχὸς expresses something obvious. Schmidt’s doubts seem excessive. In truth, the words ἕκαστον... κνώδαζιν do not repeat XI.8 [40.6-7], because, in the latter case, Hero’s remark is intended to have wider applicability.

Compare βεβηκέναι... τροχὸς with II.7 [10.17-18].

XI.10 [40.17-18] αἱ δὲ περὶ... στρέφειν. Schmidt LIII-LIV, followed by Olivieri (1901: 433) and Murphy 41 n. 22, understood the reference to ‘double cords’ (cf. also XI.10 [42.2-3]) to mean that each axle has two cords wound around it. In his opinion, this would contradict the Heronian principle that forward and backward motion is controlled by a single cord: cf. VI.1 [22.22-24.3] with note ad loc. Another implication would be that since both front wheels are in the centre of their respective axle (μεσολαβεῖν τὸν τροχόν; on Schmidt’s doubtful μεσολαβεῖν, see below), they become closer to each other (compare **Fig. 14a** with **Fig. 11a**, although in the former they appear disproportionately large) and so increase the chances of the automaton tipping over (Schmidt 381 n. 2). This may be true, but it overlooks the fact that this particular arrangement is described as favouring the even rotation of the wheels (ἐξ ἴσου στρέφειν). Unlike previous scholars, I do not think that the use of the adjective διπλός (here, as at XI.10 [42.2]) refers to the presence of two cords. LSJ s.v. I.1 give as basic meanings of διπλός ‘twofold’, ‘double’, being properly used of ‘cloaks and articles of dress’ (hence ‘double-folded’). The only examples given of the proper sense of the word are from Homer (*Il.* 4.133, 10.134, *Od.* 19.226) and Apollodorus of

Carystus (fr. 4), but this use is found as late as the Imperial period (Plu. *Mar.* 17.4; cf. Sor. *Gyn.* 4.8.14 and 4.12.3, of the posture of the foetus); cf. *DGE* s.v. A.1-2. That Hero (and not an interpolator) is using the adjective in a similar way is shown by XXIII.4 [76.5-7], where a single cord is said to have been double-wound (λαβὼν σπάρτον ἐπέιλησα διπλὴν καὶ ἐνέβαλον τήνδε ἀπλὴν εἰς τὸ τρύπημα). If the cords are double-wound, they each have three ends, two of which in the form of a loop. The axles can then each be inserted through these looped ends, each wheel being contained in the middle of the axle between the said ends. It is thus clear that Hero did not intend to double the number of cords.

I have accepted Schmid's suggestion to read μεσολαβεῖν instead of μέσον λαβεῖν. In his app. crit. Schmidt rightly pointed to XI.10 [42.3] μεσολαβοῦσα τὸν τροχόν. The verb μεσολαβέω properly means 'take in the middle' (not recorded as such in LSJ s.v.; but cf. *TGL* s.v.), but it also means, according to LSJ s.v. I, 'seize', 'nip', 'interrupt', 'intercept'. Murphy 41 n. 22 equates μέσον λαβεῖν to μεσολαβοῦσα, arguing that Hero uses these words to mean that the wheel is in the middle of the axle. However, if we were to accept the manuscript reading, we should render μέσον λαβεῖν τὸν τροχόν (μέσον being in predicative position) as 'take the middle of the wheel'; but the cords are wrapped around the axles, not the wheels: II.7 [10.14-15]. The expression μεσολαβοῦσα τὸν τροχόν, by contrast, can be understood to mean 'containing the wheel in the middle'. The closest parallel to this technical use of μεσολαβέω is the use of expressions denoting a premature death, such as μεσολαβηθεὶς τὸν βίον ὑπὸ τῆς πεπρωμένης (D.S. 11.26.8; cf. 1.3.3 ['having one's life cut short in the midst', LSJ s.v. I]) or simply μεσολαβηθεὶς... ὑπὸ τῆς πεπρωμένης (D.S. 16.1.5 and Plb. *Fr.* 184.2). The latter expression is aptly glossed by Suda μ 667 as ἐν τῷ μεταξύ [*sc.* βίῳ] συσχεθεὶς. So, μεσολαβεῖν τὸν τροχόν seems to mean συσχεῖν τὸν τροχόν ἐν τῷ μεταξύ [*sc.* ἄξονι].

XI.10 [40.18-19] **γεγονέτω δὲ... κινούμενος**. Schmidt is right to prefer **G**'s reading ἕτερος. Hero never uses the combination ἕτερος τρίτος (as in **AMT**) to introduce the third item in a series of three. This may be qualified either as ἕτερος (e.g. V.4 [22.5]) or as τρίτος (e.g. IX.1 [30.6]).

Manuscript diagrams show this axle attached to the case (see **Fig. 14a**). However, the words τούτοις ὁμοίως κινούμενος only indicate that, just like the

two front axles, the rear axle is made to turn on pivots. Following in the footsteps of Baldi 25^v unnumbered Fig. and Schmidt 378 Fig. 92a, and in analogy with the configurations for straight-line and rectangular motions, I have placed the rear axle and wheel assembly within a frame (**Fig. 14b**). It is quite possible that the original diagram has at some point been modified under the influence of the diagram for the first configuration, which in turn had been modified under the influence of the second configuration (see note on XI.2 [36.7-10]). (Note that the diagram for the second configuration is apparently now lost, and that the other two diagrams pertaining to snake-like motion are positioned next to each other in a number of manuscripts, including **A**.)

XI.10 [40.19-42.1] {ἔμπροσθεν τοῦ πλινθίου}. These words have been previously mistranslated as ‘at the front of the case’. In fact, when used prepositionally, ἔμπροσθεν means ‘in front of’ rather than ‘at the front of’ (LSJ s.v. II). Although he did not make a clear distinction between these two meanings (‘in dem vorderen... Teile des Kastens’/‘vor dem Kasten’), Schmidt 381 with n. 1 did realise that these words are inappropriate in the context. In his app. crit. he tentatively suggested emending the text and reading <ἐν τῷ> ὀπίσθεν τοῦ πλινθίου, which correctly places the axle ‘at the back of the case’. However, there are at least two reasons for rejecting Schmidt’s solution. First, Hero’s use of the adverbial pair ἔμπροσθεν/ὀπίσθεν would require us to write <ἐν τῷ> ὀπίσθεν <μέρει> τοῦ πλινθίου (cf. esp. XXIV.5 [82.21-2] ἐν τῷ ἔμπροσθεν μέρει τοῦ πίνακος). In this case, it would be more difficult to explain the combined omission of ἐν τῷ and μέρει. Second, while scribal confusion between ἔμπροσθεν and ὀπίσθεν is not uncommon (see, for instance, my app. crit. to XXIII.2 [74.12]), the exact position of the axles is always left unspecified in the treatise (Introduction, p. ciii). It is, therefore, more likely that the words ἔμπροσθεν τοῦ πλινθίου were interpolated at a later stage. We can easily imagine a rather incompetent scribe trying to describe the diagram in front of him, where the third axle would presumably have been located on the right-hand side of the case (see **Fig. 14a**).

XI.10 [42.1-2] ὥστε... πλινθίων. Schmidt 381 n. 2 found it strange that, with the addition of another axle (‘Einrichtung der zweiten Achse’ [my emphasis], no doubt referring to either of the front axles: XI.9 [40.11]), the automaton travels

on three wheels (instead of four?). I do not see how the front axles could be made to carry more than two wheels, especially considering that the wheels are now closer to each other than they were in the previous two configurations: cf. note on XI.10 [40.17-18]. Perhaps he meant to say that the rear axle should likewise carry two wheels (despite XI.10 [42.3]?), but this remains on the level of speculation.

XI.10 [42.2-3] *περὶ... σπάρτος*. The presence of a third cord was looked upon with suspicion by Schmidt LIV, because, with the exception of XI.7 [38.17-19], the third wheel is always dragged along by either or both of the front wheels: cf. XI.3 [36.19-20] and XI.4 [36.23]. This cord, however, presumably serves the purpose of giving more control over the rear wheel: cf. note on XI.7 [38.15-19]. On the doubling of the cord, cf. note on XI.10 [40.17-18].

XI.10 [42.3] *μεσολαβοῦσα τὸν τροχόν*. On the meaning of this phrase, cf. note on XI.10 [40.17-18].

A few manuscripts (**Aa**, **Bc**, **O**, **Pb**, **Vd**) have the corrupt *μεσοσυλλαβοῦσα* instead of *μεσολαβοῦσα*. LSJ s.v. give as meanings of *μεσοσυλλαβέω* 'use one remedy alternately with another' (I) and 'to be intercepted' (II, passive voice), citing, respectively, Aët. 7.45 = 108.1 Hirschberg and Alex. Aphr. *Pr.* 2.14 = 58.12-13 Ideler. As regards the first example (*μεσοσυλλαβεῖν τι ἕτερον*), which Hirschberg (1899: 107) translates as 'etwas Fremdartiges einschieben', *μεσοσυλλαβεῖν* is a variant reading for the better attested *μεσολαβεῖν* (printed by Olivieri 1950: 297; see app. crit. ad loc.). In any case, the sense demanded by the context seems to be that of 'interpose', 'interject'. The earliest and most common use of *μεσοσυλλαβέω* is in grammar, where it denotes 'intervening' parts of speech: see, for instance, Hdn. Gr. *GG* 3.1 (484.6, 484.11, 484.13) and 3.2 (161.32), Ps.-Theodos. Gr. 97.19, 109.7 and 109.19 Götting; for later references, see Bécares Botas s.v.

XII [42.9-44.14] Other movements. Lighting of the altar(s)

At this point, the discussion turns to movements that do not concern the locomotion of the automaton (XII-XVI), first among which is the lighting of the fire on either of the altars (XII.1). The device described (XII.2-4), consisting of a hearth over a sliding plate placed over a fire-grate, is strikingly similar to that used to light Nauplius' torch in the stationary automaton (XXVIII.3-7). Silences surround the ignition of the fire, but comparison with XXVIII.4 (ὅταν λύχνος καϊόμενος τεθῇ εἰς τὸ κιβωτάριον, etc.) suggests that it was performed manually during the initial setup of the automaton (Murphy 42 n. 24).

XII.1 [42.11-13] ἡ πρώτη κίνησις... βωμῷ. Brinkmann cast doubt on the authenticity of the term κίνησις, but he did not venture to emend it. In his app. crit. Schmidt hesitantly suggested emending to μῆνυσις ('revelation'), citing as support *Dioptr.* 288.22 τὰ... συμβαίνοντα μηνῦσαι. Indeed, the construction with περί is strange, but not strange enough to prompt emendation. Hero uses the verb μηνύω ('reveal', 'indicate') only once more (*Dioptr.* 298.16), but he never uses its corresponding noun. I have here followed Schmidt's translation of περί ('be-trifft' [381]).

XII.2 [42.17-18] παρακτὸν... τρύπημα. The comparison serves to illustrate the sliding of the plate, as already implied by Baldi 44^r n. 22. A γλωσσόκομον (also γλωσσόκομος) – or, less frequently, γλωσσοκομεῖον or γλωσσοκόμιον – is a 'case' or 'chest', which may be employed for different purposes; see Colace *et al.* (2001: 106-9). In his description of the water organ, Hero uses the term in a technical sense with reference to a series of 'compartments' (*Spir.* 196.5, 198.5, 198.13-14, 200.2, 200.5, 200.14); see LSJ s.v. γλωσσοκομεῖον. Interestingly, the apertures of these compartments have sliding lids to close them (cf. *Spir.* 196.7-11). For a related use of the term, we must turn to medicine, where γλωσσόκομον – and not γλωσσόκομος, as with LSJ s.v. II – refers to a machine for setting broken bones (*Gal. Meth. Med.* 10.442 Kühn, Orib. 49.7, 49.21 [chest of Nymphodorus]); see *DGE* s.v. γλωσσόκομον and Drachmann (1963a: 172-3, 176-8). The chest of Nymphodorus is described as having πώματα... χάριν τοῦ κρύπτεσθαι τὰ ἐν αὐτῷ μηχανήματα (Orib. 49.21.7; cf. 49.23.25 [*trispaston* of

Apellis or Archimedes]); on surgical traction machines more generally, see Wilson (2008: 345-6).

The verbal adjective παρακτός is not recorded by LSJ, but seems to be attested only here. Both Baldi 26^r and Couture 255 omitted translating it, whereas Schmidt 381 rendered it correctly ('das sich... verschieben lässt'); Murphy 22, less correctly, has 'which can *slide*' (my emphasis). For the formation of verbal adjectives in -τος, cf. KB 2.288-9. The verb παράγω, from which παρακτός is formed regularly, occurs in the *Automata* at XIX.2 [62.2] (passive) and XIX.3 [62.3], both referring to the act of sliding the κλειθρίον (on which, see note on IX.5 [32.8-9]). Cf. XII.3 [44.1] (παραλλάσσω). This use of the verb is consistent with the way it is used in the *Pneumatica* with respect to a weight that is shifted along a rod: *Spir.* 288.6, 294.13, 294.14, 294.20, 296.5. Cf. also the corresponding noun at XXVI.6 [94.16] (παραγωγή).

XII.2 [42.19] ἄξόνιον ἐντὸς τοῦ βωμοῦ κείμενον. Hero does not specify whether the axle is vertical or horizontal. Schmidt LIV argued that a vertical ἄξόνιον, such as is found in the manuscript diagrams (see **Fig. 15**), would entail a considerably smaller altar (a vertical axle should be an ἄξων, according to his line of argument), and so made it horizontal (Schmidt Fig. 93b). This openly contradicts his claim that Hero most likely intended to describe the device for kindling the fire on the altar in a similar way to the mechanism of Nauplius' torch (XXVIII.3-7 [102.3-104.10]; **Fig. 32**), where, apparently, the axle is vertical. It seems to me that he has attached too much importance to the diminutive value of the term ἄξόνιον ('kleine Achse', Schmidt 383). The size of the (vertical) axle will rather depend on the size of the altar. Murphy 42 n. 23 wanted the altar to be square (and not rectangular, as in **Fig. 15**), with sides measuring one-half to one palm (3.85-7.71 cm).

XII.3 [42.21-2] ἐκ δὲ τοῦ... <***>. I accept Schmidt's doubtful suggestion to read ἐκ... τοῦ ἄξονίου instead of ἐν... τῷ ἄξονίῳ ('on the axle'; thus Murphy 22, who mistakenly construes ἀποδεδόσθω with ἐν + dative). Cf. XII.2 [42.18] ἐκ δὲ τούτου [i.e. λεπίδιου] ἄλυσείδιον... ἀποδεδομένον, etc. As an alternative, Schmidt (app. crit. ad loc.) suggested a lacuna after ἄξονίῳ, albeit without indicating its size. He seems to have thought that the lacuna should have contained

information on the winding of both the chain and the cord around the axle and, possibly, on the attachment between the two (Schmidt LIV). The chain and the cord, however, need not be connected to each other (see further note on XII.4 [44.8-9]). The most important piece of information missing, it seems to me, is the presence of some slack in the cord (cf. XII.4 [44.13]). It is thus necessary to posit a lacuna somewhere in the sentence, but the word order suggests that something dropped out after σπάρτος – perhaps <χάλασμα ἔχουσα>? Cf. esp. XI.4 [36.21-2] and XIII.5 [46.20-1]. Positing a lacuna after ἄξονίου (or ἄξονίῳ) would probably imply that the noun σπάρτος has been misplaced: cf. XVIII.1 [58.15] (ἐκ δὲ τοῦ ἐξ ἄξονος ἑτέρα σπάρτος ἐκδεθεῖσα) and *Dioptr.* 202.5-7 (ἐκ δὲ τοῦ χελωναρίου σπάρτος ἐκδεθεῖσα).

XII.3 [44.1-2] τῆς ἀγκύλης...τύλου. Schmidt was rather confused by these words. In his app. crit. he suggested either transposing them after XII.3 [42.22] (μετὰ τὴν πορείαν) or deleting them altogether, but not without noting the almost identical expression at II.9 [12.14-15] (ἐκπεσούσης τῆς ἀγκύλης ἀπὸ τοῦ τύλου). However, in his *Anmerkungen* (Schmidt LIV), he speculated that Hero might be referring, just as he does at XXVIII.7 [104.10] (cf. δ in **Fig. 32**), to a knob on the ἄξονιον (as opposed to that found on the ἐξελίκτη: see Schmidt 383 n. 2). An obvious objection to the latter interpretation is that, if a cord falls off its knob, the transmission of movement is interrupted (cf. note on II.9 [12.14-15]). What follows, XII.3-4 [44.3-11], describes instead the operation of the fire-starting mechanism. Likewise, I am reluctant to believe that these words were interpolated, mainly for stylistic reasons (in addition to the passage quoted, cf. V.5 [22.19-20]). A transposition would certainly contribute to bringing order into the text, but it does not accord with the way information is arranged (see Introduction, p. cxvii).

XII.3 [44.2-3] τὰ ἐξῆς ἐπιτελεσθήσεται. It does not seem to refer to what immediately follows. See note on I.1 [2.7-8].

XII.3 [44.3-4] λαμπτήρ...τροπήματι. Manuscript diagrams agree in showing the λαμπτήρ suspended in air (see **Fig. 15**), which is clearly absurd. The grate must have been provided with one or more supporting legs. Hero does not give any

information about how to light the fire or to keep the flame burning before the sliding of the lid, a fact paralleled later on at XXVIII.3-6 [102.3-4.4]. In his description of the mechanism of Nauplius' torch, he insists that the flame must remain hidden until it is convenient to light the torch: XXVIII.5 [102.20-2]. There is no reason to suppose that the same is not true here. Murphy 42 n. 23 rightly pointed out that, in order to keep the fire from being extinguished too soon, the altar should not be airtight.

The term λαμπτήρ occurs only once more in Hero (XXVIII.6 [104.3]), but, as the context makes clear, with a different meaning ('lantern', LSJ s.v. 2).

XII.3 [44.4-6] ἐπικείσθω... ἀνάπτεσθαι. Cf. III.4 [16.18-20] with note ad loc.

M has the obviously incorrect ὑποκείσθω. This variant reading probably arose under the influence of XII.3 [44.3]. Cf. also the immediately preceding ὑποκειμένην.

XII.4 [44.8-9] ἡ... ταθεῖσα. I take the phrase ἡ... σπάρτος to mean that the cord comes from the direction of the chain (as shown in **Fig. 15**), understanding ἐκ loosely. Cf. XVI.3 [56.5] and XIX.3 [62.5-6]. This is also suggested by the similar description of the mechanism of Nauplius' torch: cf. XXVIII.7 [104.7-10]. Perhaps we should add <ἀποδομένη> or <ἀποδεδομένη> before σπάρτος. Compare, in addition to XIX.3 [62.5-6], XXVI.8 [96.9]; but cf. XXVIII.7 [104.10]. Conversely, Schmidt (app. crit. ad loc.) tentatively proposed adding <ἐκδεθεῖσα> after σπάρτος, a supplement which, in spite of the doubts raised in the *Anmerkungen* (Schmidt LIV; cf. note on XII.3 [42.21-2]), he adopted in his translation: 'die an das Kettchen gebundene Schnur' (Schmidt 1899a: 383 with n. 3). It would, however, have been more correct if <ἐκδεθεῖσα> – or even <ἐκδεδεμένη>, cf. XIX.4 [62.14] – had been put before σπάρτος. Similarly, but without any supplement, Murphy 22: 'the cord stretched from the chain' (ἡ... ταθεῖσα σπάρτος?). Baldi 26', followed by Couture 255-6, has the cord pulling on the chain: 'la catenella g, h, k, tirata dalla [ὑπό?] corda'.

XII.4 [44.11-13] τὰ δ' αὐτὰ... εἰρημένον. No cord slack has been previously mentioned in connection with the kindling of the fire, a fact that has escaped the attention of previous scholars. For the suggestion that such reference dropped

out of the text, cf. note on XII.3 [42.21-2]. In the case of the other altar, a greater slack is needed to activate the device at the appropriate time; cf. V.5 [18.15-16].

XII.4 [44.13] **κατὰ τὰς ἐξῆς κινήσεις**. Brinkmann's emendation *μετὰ*, anticipated by Baldi 26^v ('dopo'), is attractive but unnecessary, since the reading of the manuscripts (*κατὰ*) makes sense if we take *τὰς ἐξῆς κινήσεις* as referring to the second series of movements constituting the apotheosis of Dionysus (cf. synopsis on III-IV). This is not implausible, considering that the reader has been invited to focus his or her imagination (*τὰ δ' αὐτὰ ἐπινοείσθω*, XII.4 [44.11]) on the second altar. For the scribal confusion between *κατά* and *μετά*, see app. crit. to V.3 [22.2].

XIII.1-7 [44.15-48.13] Pouring of liquids

Milk and wine are conveyed through a hidden piping system leading from a double reservoir placed within the upper part of the shrine's roof to two vertical columns, which are fitted one inside the other underneath Dionysus. The flow is regulated by a tap (κλείς) which, unlike extant specimens of the Roman period, admits two pipes. Details of the operation of the tap are discussed in the notes ad locc. Prou 170 n. 157 argued that since the liquids are poured twice (πάλιν δὲ... γάλα, XIII.5; cf. IV.1 and 3), the holes in the thyrsus and the cup should be closed between the first and the second libation. Considering that the system works thanks to the principle of communicating vessels (as acknowledged by Prou 170), it would probably have been enough to turn off the tap.

XIII.2 [44.17-18] **ὑπὸ... σωλῆν**. Murphy 42 n. 25 maintains that the pipe is no longer than one palm (7.71 cm), a measure which she equates to the sum of the thickness of the shrine's platform (κατάστρομα), the shrine's floor and the base of Dionysus (cf. XIII.3 [46.1]). Hero, however, does not provide any measures for these elements. Manuscript diagrams show the pipe as extending all the way down to the automaton's base (see **Fig. 16**). This is clearly impossible, because it does not leave much room for other components, such as the σύριγξ and, possibly, the wheel and axle assembly. The pipe could not extend down beyond the architrave (ἐπιστύλιον, cf. notes on III.1 [16.2-4]), and had to pass through the

stylobate (XVI.1 [54.11]), as illustrated in Baldi 27^v unnumbered Fig. and Schmidt 387 Fig. 94a.

Schmidt suggested adding <τούτῳ> after συμφυῆς, comparing XIII.3 [46.1-2] ὁ δὲ συμφυῆς τούτῳ [i.e. τῷ Διονύσῳ] σωλήν. This supplement is attractive, since συμφυῆς seems to require a dative (see LSJ s.v. II.2). It is also easy to explain palaeographically (γίνεται οὖν καὶ τοῦτο οὕτως... συμφυῆς <τούτῳ> γίνεται σωλήν). However, <αὐτῷ> would work equally well. Cf. esp. *Spir.* 270.24-6 Ἔστω γὰρ ὑπὸ τὴν λυχνίαν ἀγγεῖον... ἦτοι συμφυὲς αὐτῇ ἢ καὶ ἰδίᾳ κείμενον. Cf. also *Dioptr.* 194.9 and 246.15.

XIII.2 [44.19-21] ἐκ δὲ τούτων... σκύφον. Unlike previous editors, I adopt **G**'s reading ἀνατείνονται, which **A** and **T** correct *supra lineam* to ἀνατείνοντα, perhaps under the influence of the following φέροντα (but cf. also XIII.3 [46.2-3]). A finite verb is needed to make the sentence complete, as also shown by previous translations. φέροντα (**AG**) is obviously a better reading than συμφέροντα (**MT**). Cf. XIII.3 [46.7], XIII.4 [46.12], XIII.6 [48.4] and XIII.7 [48.12].

XIII.3 [46.2-4] τὰ δὲ... σκύφον. I deem it unnecessary to add <φέροντα> after εἶθ, as tentatively suggested by Schmidt (app. crit. ad loc.) on the basis of the previous occurrence of the participle (XIII.2 [44.20]). The sentence makes good sense in its present form, if we suppose ἀνατείνοντα to be understood. In contrast to XIII.2 [44.19-20], the verb ἀνατείνω here is not immediately followed by a prepositional phrase introduced by εἰς.

XIII.3 [46.4-6] ἔστω δὲ... νξ. According to LSJ s.v., the term πυρήν primarily denotes the 'stone' of a stone-fruit (I.1), but it may also refer to other (semi-)round objects, such as a pine 'nut' (I.2), a 'grain of frankincense' (III.a), a 'head of a probe' (IV.1) and a 'gem' (V; cf. Prêtre 1997b: 372 with n. 4). Here it seems to denote a 'knob' (so also Murphy 23; cf. XXVI.2 [90.18] πυρηνίδια) resting on the summit of the roof (cf. note on III.2 [16.8-10]; **Fig. 16**). Most translations render the term incorrectly, as if it were πυργίον: 'cupola' (Baldi 26^v), 'concameratus apex' (Couture 256), 'Dach' (Schmidt 385).

Murphy 42 n. 26 makes two points here. The first is that the πυρήν probably serves either as an ornament or as a base for the Nike. The second is that the

container $\overline{\nu\zeta}$, along with the axle $\overline{\xi\zeta}$ and the pulley $\overline{\eta}$ (cf. XIII.7 [48.15-17]), is actually placed inside the roof. The $\pi\rho\eta\eta\nu$ is not simply ornamental. Not only does it serve as a support for the Nike (XIII.7 [48.14]), but it also holds the container $\overline{\nu\zeta}$ (ἐντὸς δὲ τούτου... $\overline{\nu\zeta}$). The axle $\overline{\xi\zeta}$ is described as passing through the knob (how else could it be attached to the Nike?), and certainly extended down into the roof ($\kappa\alpha\theta\epsilon\acute{\iota}\sigma\theta\omega$... διὰ τοῦ $\pi\rho\eta\eta\nu$ ος, XIII.7 [48.14-15]). On the thickness of the axle, cf. XIII.8 [50.4-5]. No information is given on the location of the pulley, but nothing suggests that it should be placed inside the knob.

Most manuscript diagrams show a rectangular support at the top of the roof, and label the whole roof (containing all the above-mentioned elements) $\kappa\lambda\mu$ (see **Fig. 16**). Similarly, but with a round projection supporting the Nike, Schmidt 386 Fig. 94a and Murphy 24 Fig. 7. Baldi 27^v unnumbered Fig., by contrast, has the Nike directly resting on the apex of the roof.

XIII.3 [46.9-10] τῷ καταστρώματι ἐφ' ᾧ ὁ ναῖσκος ἐπίκειται. Cf. III.2 [16.5-7].

XIII.4 [46.11-13] ἐκ δὲ τοῦ... σωλήνα. I follow Schmidt in marking a lacuna after ἀγγείου. The lacuna must have contained the main verb. In his app. crit. Schmidt doubtfully proposed two supplements, <καθείσθω> and <φερέτω>, citing in support of the latter XIII.3 [46.7] and XIII.6 [48.4]. <φερέτω> is better than <καθείσθω>, because in the *Automata* the verb καθίημι never refers to pipes, a usage otherwise common in the *Pneumatica* (see, for instance, *Spir.* 72.14-74.1, 74.6 and 104.2). However, <φερέτω> involves the deletion of καὶ φέρων, which would result in ὁμοίως being misplaced. Hildebrandt's καταφερέτω for καὶ φέρων does not strike me as a very plausible emendation. While it has the advantage of eliminating the lacuna, it is difficult to explain palaeographically. Furthermore, the verb καταφέρομαι, as used in the treatise, refers not to pipes bearing downwards, but to falling bodies; see note on V.5 [22.16-17]. Perhaps we could fill the lacuna with <ἔστω>, limiting ourselves to the deletion of the καί. Cf. *Spir.* 114.5-7 ἐκ δὲ τοῦ πυθμένος σωληνάρια ἔστω... φέροντα εἰς ἓνα κρουνίσκον κοινόν.

XIII.4 [46.14] $\overline{\sigma\nu}$. Perhaps emend to $\overline{\nu\sigma}$. Cf. XIII.3 [46.6].

XIII.5 [46.18] ἵν' οὖν στέγῃ τὰ ὕγρὰ. The subject of στέγῃ is the following κλείς, which explains Hero's reference to what has already been said (ὥς εἴρηται, XIII.5 [46.19]). Baldi 26^v, Couture 256 and Schmidt 385 mistook τὰ ὕγρὰ as the subject and translated the verb as if it were passive. Murphy 23, by contrast, has the correct rendering. Hero always uses στέγω in the sense of 'keep in', 'hold' (*Geom.* 414.14, *Spir.* 62.7, 78.13, 102.6 and 294.1). For the verb in this sense, see LSJ s.v. B.I.

XIII.5 [46.18-19] κλείς... ἐπιτόνιον. For a discussion of ancient taps (surviving from Roman times), see Kretzschmer (1960). See also, more recently, Hodge (1981: 489-91; 1992: 322-6), who emphasises the distinction between two kinds of taps: 'discharge taps' and 'stopcocks'. Hero's tap is a stopcock, as it is used to regulate the flow of liquids rather than to dispense them through an outlet spout. An ancient tap, regardless of its function, usually consisted of a cylindrical plug (also called key) perforated by a horizontal hole (or pair of holes) and rotating inside a cylindrical housing (**Fig. 17**). Hero's stopcock was presumably perforated with two pairs of holes, each admitting one of the conveying pipes (cf. XIII.3-4 [46.6-13]). This is illustrated, albeit in a very rudimentary fashion, on the lower right-hand side of **Fig. 16**. For a modern reconstruction, see **Fig. 18**.

Hero uses two different words, κλείς and ἐπιτόνιον. κλείς (lit. 'key') synecdochically signifies the whole device ('tap' or 'stopcock'). It also occurs at *Spir.* 124.16, the only occurrence of this meaning given in LSJ s.v. II.2. Elsewhere Hero uses the derivative κλειδίον (Drachmann 1948: 50; cf. LSJ s.v. I.2): *Spir.* 122.14, 190.18, 212.16, 266.24, 268.10, 268.16, 274.10 and 274.18. The synecdochic extension of meaning can still be seen in It. 'chiave' (Baldi 27^r, with Manni 1980: 178-9, 195) and Lat. 'clavis' (Couture 256). The equivalent French term has been used by Prou 170, but he appears to have understood it in its proper sense: '[u]ne clef', κλειῖς [*sic*], adaptée à une *douille* obturatrice, ἐπιτόνιον'. Schmidt 385 and Murphy 23 have, respectively, 'Verschluss' (but cf. 'Hahn', Schmidt LV) and 'valve' (or 'bolt'(?)). The word ἐπιτόνιον, which previous translators have misunderstood to mean 'tap'/'stopcock' (cf. also Soubiran 1969: 304; Argoud-Guillaumin 1997: 150 n. 19), signifies the 'plug' or 'key' of a tap ('clef cylindrique', E. Saglio in DS 2.711 s.v. *Epistomium*). It originally denotes a 'tuning peg' or 'key', and has been extended to apply to the handle of

either a tap (here) or σμήρισμα (*Spir.* 250.16-17, 250.25, 252.3 and 252.8; cf. *Vitr.* 9.8.11). Hero also uses it for the handle of a syringe (*Spir.* 254.2 and 254.8); see LSJ s.v. II.1; Puchstein (1907: 203); Drachmann (1948: 50, 60). The term seems to occur in the sense of ‘tap’ only at Ps.-Hero, *Spir.* 146.18-19 κλειδίον... τὸ καλούμενον **παρὰ τοῖς πολλοῖς ἐπιτόνιον**. This looser, popular sense is commonly attested in Latin (*epitonium*: Varro, *RR* 3.5.16, *Vitr.* 10.8.3, 10.8.5, 10.8.11, Seneca, *Ep.* 86.6 and Ulp. *Dig.* 19.1.17.8). On this term, as opposed to the incorrect *epistomium*, cf. Cagnat (1894). Baldi 44^v n. 24 glossed his translation (‘galletto’, with Manni 1980: 178-9, 199) with the word ‘epistomio’. This has been taken to mean that his exemplar had the word ἐπιστόμιον (Manni 1980: 178 n. 3, cited by Micheli 2005: 253 n. 24). I have found no such reading in the manuscripts. This alternative form was coined in the Renaissance (Puchstein 1907: 203, quoted by Drachmann 1948: 60), probably by analogy with *epistomium*.

I accept Brinkmann’s suggestion (endorsed by Schmidt LV and Olivieri 1901: 433) to read λ (in $\overline{\tau\lambda}$) instead of τ . Cf. also XIII.6 [48.7]. τ , in fact, already denotes a hole. Schmidt LV observed that in earlier manuscripts λ was written as Λ (more or less pointed) and that the latter form could easily be corrupted into tau. His basic point is right, but it overlooks the fact that the symbol for 900 (*sampi* or *παρακύϊσμα*) could also occur in the form Υ (among others). On the various forms of *sampi/παρακύϊσμα*, see especially Foat (1905; 1906); for a more complete bibliography, see Soldati (2006: 209-10 n. 4).

XIII.5 [46.20-3] **περὶ δ... ὑγρά**. The participles ἔχουσα and ἀποδοδομένη should not be regarded as irremediably corrupt (ἰᾷχουσα καὶ ἀποδοδομένη Schmidt, suggesting in his app. crit. emendation to the genitive case), but rather as hypallage for ἐχούσης and ἀποδοδομένης. The subject of ἐπιστρέψῃ is clear enough from the context, but perhaps the words <ἡ σάρτος> have dropped out after ταθεῖσα (**AGT** have σάρτος instead of the correct σάρτου). Cf. XII.4 [44.14].

This cord must have turned the tap 90 degrees (either clockwise or anti-clockwise) in order to align the holes in the plug with the conveying pipes (cf. previous note). Another 90-degree turn (in either direction) would have been enough to shut off the tap; see Hodge (1981: 490 n. 24; 1992: 324). This means either that four different cords were used to rotate the plug 360 degrees in the

same direction or that the stopcock was turned on and off (with a 180-degree arc of rotation) by two cords, each pulling in a different direction. The mention of another cord drawing the ἐπιτόνιον in the opposite direction (εἰς τὰ ἕτερα μέρη) suggests the latter: XIII.6 [48.8-10]. There, perhaps, we should read κλείεται in place of ἀνοίγεται. See further note ad loc.

Manuscript diagrams show no cord wrapped around the ἐπιτόνιον (see **Fig. 16**). Schmidt 387 Fig. 94a and Murphy 24 Fig. 7 have only one cord. Baldi 27^v unnumbered Fig., more correctly, has two. Murphy added next to her diagram: ‘This cord goes to a counterweight (probably MB): Hero doesn’t explain’ (see also Murphy 42 n. 29). Hero’s use of the article (εἰς τὴν λείαν), however, is a strong indication that the cord was attached to the main counterweight rather than to ^βμ (XIII.8 [50.9]). See Schmidt (1903: 275-6).

XIII.5 [46.23-48.1] **πάλιν δὲ... γάλα**. I take the first πάλιν to refer to the content of the main clause (δεῖ... γάλα). I am tempted to delete the second πάλιν, but perhaps the repetition is merely emphatic. Baldi 27^r, Couture 256 and Murphy 23 understood the first πάλιν as modifying the genitive absolute ἐπιστραφέντος τοῦ Διονύσου, which erroneously places the second libation after the second rotation of Dionysus. That would probably require a different word order (ἐπιστραφέντος δὲ πάλιν τοῦ Διονύσου). Cf. XXII.5 [72.14-15] (original word order?). Schmidt 389 (‘dagegen’) curiously assigned an adversative value to the first πάλιν.

XIII.5 [48.1-2] **στρέφεσθαι... ἡμικυκλίου περιφέρειαι†**. I here follow the punctuation of **AGT (M)**, too, punctuates heavily after οὕτως). Schmidt 386, followed by Murphy 23, placed a full stop after περιφέρειαι, but did not punctuate after the adverb. The opening words, however, seem to have been intended to precede an explanation (cf. XII.2 [42.14], XIII.2 [44.17], XIII.7 [48.13-14], XIV.1 [50.17-18], XV.2 [52.9], XVI.1 [54.9-10], XVII.1 [56.12-13], XIX.2 [60.18-19], XXII.3 [70.19], XXV.4 [86.15], XXX.5 [108.14]; cf. also XXVI.1 [90.10] and XXVIII.2 [100.11]). We can therefore dismiss Schmidt’s doubtful suggestion (app. crit. ad loc.) to read στρέφεται δὲ οὕτως ἡμικυκλίου περιφέρειαν, where the accusative περιφέρειαν is governed by στρέφεται (for comparable examples, cf. LSJ s.v. στρέφω I.2). Brinkmann’s conjecture οὗτος [i.e. Διόνυσος] for οὕτως

is not very convincing either. All previous translators, except Murphy 23, understood the corrupt στρέφεσθαι as referring to the rotation of Dionysus rather than that of the stopcock (but see Murphy 42 n. 27, where she acknowledges the ambiguity of the text). A reference to the latter – or, more correctly, to the ἐπιτόνιον – would fit better within the context, not least because the rotation of Dionysus is discussed later on (XIII.7-9 [48.13-50.14]). A more serious difficulty lies in the words ἡμικυκλίου περιφέρεια (†περιφέρεια Schmidt). First of all, they have no syntactic connection to the immediate context. Second, they might equally apply to the first rotation of Dionysus (cf. XIII.5 [46.23]) and to the overall rotation of the ἐπιτόνιον (cf. note on XIII.5 [46.20-3]). Baldi 27^r, followed by Couture 256, unintelligibly construed περιφέρεια as the subject of the following γεγονέτω ('[s]i faccia la periferia, ò circonferenza, d'un mezo circolo per diametro à i fori, t, s'), which, among other things, leaves ἕτερα τρήματα standing alone (XIII.6 [48.3-4]). I have put these words between *crucis*, wondering whether they represent a marginal scholium that was incorporated into the main text and was originally intended to elucidate the rotation of either Dionysus or the ἐπιτόνιον. As regards στρέφεσθαι δὲ οὕτως, a finite verb is certainly needed. Schmidt's στρέφεται is attractive in itself, but perhaps it would be better to emend to ἐπιστρέφεται and to place a lacuna after δὲ (ἐπιστρέφεται δὲ <τὸ ἐπιτόνιον> οὕτως?). In addition to XIII.7 [48.13-14], cf. XIII.5 [46.22].

XIII.6 [48.3] **γεγονέτω**. This reading is preferable to γενέσθω, although the latter is handed down by the best manuscripts (**A**^{ac} reads γεγονέτω); see note on XI.9 [40.8-9].

In his app. crit. Schmidt hesitantly suggested adding either <δὲ> or <οὖν> after the imperative. A connective particle would indeed be very welcome. The omission of δὲ would be easy to explain (στρέφεσθαι δὲ οὕτως... γεγονέτω <δὲ>), all the more so if the words ἡμικυκλίου περιφέρεια had been added at a later stage (cf. previous note). However, <γὰρ> would seem to fit better in the context. Cf. XI.8-9 [40.7-8] (ποιήσομεν οὖν οὕτω· γεγονέτω γὰρ, etc.) and *Spir.* 32.7 (οὕτως ἀποδείξομεν· γεγονέτω γὰρ, etc.), the only two occurrences of the sequence γεγονέτω γὰρ in Hero. The tachygraphic sign for γὰρ – in its simplest form, Γ cut across by a left oblique stroke (Allen 1889: Pl. III nos. 1-2; Gardthausen 1913: 336) – could just as easily have been omitted.

XIII.6 [48.8-10] ἀνοίγεται... μέρη. Most manuscripts read here εἰς τὰ ἕτερα βάρη. This reading does not make sense because no weights have been mentioned in the preceding context. Schmidt puts a *crux* before βάρη, but translates his doubtful emendation μέρη (cf. already Baldi's 'parte', 27^r), which he supports by citing XIII.8 [50.3] ἐπὶ τὰ αὐτὰ... μέρη (of the rotation of Dionysus and Nike). This conjecture not only fits perfectly well into the context (we would indeed expect a reference to the direction of the cord: cf. note on XIII.5 [46.20-3]), but is also palaeographically plausible. The corruption probably arose from the common confusion between minuscule μ and β.

Schmidt hastily deleted the words ἀνοίγεται... †βάρη as an interpolation. In his opinion (LVI), Hero's own principles demand the use of only one cord. While it is true that a single cord controls forward and backward motion (cf. VI.1 [22.22-24.3] with note ad loc), it is not clear how the ἐπιτόνιον could be rotated – back and forth? – by fewer than two cords. In order to allow repeated operation of the stopcock, the cords presumably had some slack to them. Using fewer than two cords would have meant a cord of excessive length. What is striking here is not so much the reference to a second cord, but rather the reference to the opening of the stopcock. Hero never mentions how the stopcock is closed. If two cords were indeed used, each one pulling in a different direction, one would expect a reference to the closure of the stopcock. One cannot help but wonder whether an original κλείεται was at some point replaced by ἀνοίγεται, possibly under the influence of ἀνοιχθήσεται in the preceding line.

XIII.7-9 [48.13-50.15] Rotation of Dionysus and Nike

The inner column underneath Dionysus is connected, by means of a hidden cord (καὶ... κρυπτέσθω, XIII.9), to an axle that lets the Nike rotate (XIII.7). The column rotates 180 degrees twice (as suggested by XIII.8 ὅπως... θέσιν; cf. synopsis on III-IV), the movement being imparted by a falling weight, which is released by a trigger (σχαστηρία) of the kind used in catapults (XIII.9). Hero does not say whether the second rotation occurs in the same direction, which, however, is implied in the use of the verb ἀποκαθίσταμαι (XIII.8). Prou 169 imagined an intermittently rotating shaft extending from the base of the automaton to the figures of Dionysus and Nike (how so?) and provided with a bob-

bin to change the direction of turning. This arrangement is nowhere described in the text.

XIII.7 [48.14-15] **καθείσθω... ,ξζ.** On the position of the axle, cf. note on XIII.3 [46.4-6].

XIII.7 [48.17] **περιεληθεῖσα σπάρτος.** The word σπάρτος is omitted by most manuscripts, including **a**. It appears to be a conjecture in manuscript **Aa** ('σπάρτος [*sic*] f.'), and is replaced by the words ἀγγύλη [i.e. ἀγκύλη?] σπάρτου in the margin of **M** (second hand). If this word originated as a scribal conjecture (a very plausible one indeed) intended to fill a gap, one might wonder whether the original reading was ἄλυσις instead. Hero's later reference to 'another chain' to be wound around pipe γδ̄, XIII.8 [50.7], is somewhat perplexing. In this regard, Baldi 44^v n. 25 noted that there is no reason to expect a chain rather than a cord, all the more so because no chain has been mentioned in the preceding context. He went on to suggest that perhaps Hero has in mind the chain used to slide the plate inside the altar (XII.2 [42.18], XII.4 [44.9]). This is certainly a possibility. But why would Hero use a cord and a chain instead of two cords or two chains? The verb περιελέω is used nine times by Hero in connection with cords (in the *Automata* only), whereas it refers only once to the winding of a chain (XXVIII.7 [104.8]).

XIII.7 [48.18-19] **τὸ ὑπερέχον τοῦ γδ̄ σωλήνος.** For the substantivised participle of ὑπερέχω with a subjective genitive, cf. XXIV.3 [82.6] (ἐπίουρος) and, in other mechanical writers, Ph. *Bel.* 66.15-16, 72.25-6 and 72.30-1. XXVI.4 [92.12] (τὸ ὑπερέχον τοῦ πίνακος) illustrates a different use of the genitive (for instances, see LSJ s.v. II.1).

Note the *variatio* with XIII.8 [50.8] (ὑπεροχή).

XIII.8 [50.3-4] **ἐπὶ... αὐτῶν.** This is rendered possible by the use of pulleys ,η̄ and ,θ̄. Cf. XIII.7 [48.16-19].

XIII.8 [50.4-5] **ἴσος δὲ... σωλήνι.** ἄξων here seems to designate the shaft of the axle rather than the entire axle (see already Schmidt 389). Manuscript diagrams

show something like an ἐξελίκτηρα around the centre of axle $\overline{\xi, \zeta}$ (see **Fig. 16**). This seems to be intended to make the diameter of the axle shaft equal to the diameter of the pipe, and so produce equal rotations (cf. note on II.10 [12.18-19]). For the same purpose, Murphy 24 Fig. 7, explicitly following Schmidt 387 Fig. 24a, added a drum at the base of the axle. This already appears in Baldi 27^v unnumbered Fig., and might have originally been based on the manuscript illustration.

XIII.8 [50.5-6] ὅπως... θέσιν. The verb ἀποκατασταθῶσιν is mistranslated by Baldi 28^r ('si fermino') and Couture 257 ('conquiescant'). Here it implies that the figures of Dionysus and Nike complete their rotation ('come back *full circle*', Murphy 23; my emphasis); see note on I.2 [2.13-14]. Schmidt 389 ('in ihre frühere Stellung zurückkehren') is therefore right to take θέσιν as referring to the original position of the figures. Baldi 28^r, less appropriately, has 'postura' (στάσις? see LSJ s.v. B.a.2). Similarly, but more generally, Couture 257 ('positu'). Murphy 23 slips into overinterpretation ('relative position'). I am tempted to restore here: μηδὲν παραλλάσσοντες κατὰ τὴν <ἐξ ἀρχῆς> θέσιν. In addition to I.2 [2.13-14] and the passages cited in the note ad loc., cf. *Metr.* 94.16-17 τὸ... τῆς ἐλλείψεως ἐπίπεδον ἀεὶ παράλληλον ὑπάρχειν τῇ ἐξ ἀρχῆς θέσει.

XIII.8 [50.7] ἑτέρα ἄλυσις. Cf. note on XIII.7 [48.17].

XIII.8 [50.9] τὸ μ^B . On the secondary counterweight, see note on II.6 [10.8-10].

XIII.9 [50.10-11] ὁ δὲ... γίνεται. The words καθάπερ... γίνεται have been strangely understood by Schmidt LVI as a reference to Hero's own *Belopoeica*. In his opinion, they apply only to the σχαστηρία ('trigger'), and not to the χεῖρ ('claw'). This is somewhat curious, given that the claw is an integral part of the trigger mechanism of a torsion engine. The whole mechanism is first attested in non-torsion artillery ('belly-bow' or γαστραφέτης, cf. Hero, *Bel.* 78.2-79.5), as illustrated in **Fig. 19**. The claw, which was used to draw the bowstring, could either have two prongs (as in the γαστραφέτης) or only one, depending on the type of engine (euthytone or palintone, cf. *Bel.* 110.11-111.6; on the distinction between these two types of engines, see Marsden 1969: 20-3; 1971: 44-5 n. 5

with Fig. 1; see also, more recently, Schiefsky 2005: 254). In palintones or stone-throwers, the bowstring was plaited into a ring (κρίκος) at its middle point, and the prong of the claw was fitted into it (Marsden 1969: 32). Schmidt LVI cast doubt on whether the χεῖρ would have worked correctly here, but what he had in mind was a two-pronged claw: ‘zweier handartig gebogenen Stifte’ (391). I am inclined to think that here, as in the case of palintones, Hero adopts a one-pronged claw to be fitted into the κρίκος (**Fig. 20**).

It is unnecessary to emend κατεχέτω to κατεχέσθω or even κατέχεται, as suggested by Brinkmann. The weight is retained by the ring, just as at XV.3 [54.2] the boards used to release the garlands are held in place by a rotating hook (ἐπιστρεπτῷ κόρακι κατέχεται). The claw will have disengaged from the ring upon the release of the trigger, allowing the weight to fall down (XIII.9 [50.12-13]). Here previous translators, except Schmidt 389, render κατεχέτω as if it were passive. See especially Murphy 23 (‘Let a ring... be *controlled*’; my emphasis).

XIII.9 [50.12] **ἀπό**. In Hellenistic Greek the preposition is commonly used to denote agency; see LSJ s.v. A.III.4 and, more recently, Bortone (2010: 185 with n. 28). Thus we need not emend to ὑπό, as tentatively suggested by Schmidt (app. crit. ad loc.). Cf. *Spir.* 152.6-7 (ἀφ’ ἐκάστου ἐμβληθείς), already cited by the Teubner editor. For the confusion between ἀπό and ὑπό, see app. crit. to XIV.1 [50.21]. Cf. also XXII.6 [72.17].

XIII.9 [50.15] **καθάπερ... εἴρηται**. Cf. XIII.7 [48.11-13].

XIV [50.16-52.6] Sound of kettledrums and cymbals

The device discussed here is comparable to that described at XX.4 (βροντεῖον), except that the latter does not include a cymbal (Murphy 42 n. 32). The basic form of the device is simply a container holding lead balls which are released to hit the instruments (XIV.1-2 ἐν τῇ... ἀποτελέσει). There follows a modified version of the device, with balls being distributed into two compartments. The opening of the description (XIV.2 δύνανται... ποιῆσαι) seems to suggest that this second version represents an improvement made by Hero. See Introduction, p. cxii.

XIV.1 [50.16-17] **κυμβάλων καὶ τυμπάνων κτύπον**. Cf. IV.2 [18.10-11] (ἦχος) and IV.3 [18.19-20] (ψόφος), but here the word order is reversed. The term κτύπος usually denotes an abrupt noise, like thunder (A. *Pr.* 923; S. *OC* 1463) or the shutting of a gate (Aen. *Tact.* 20.4), and is only rarely used of musical instrument sound. LSJ s.v. record only one instance of this use: B. *Fr.* 3.9 Jebb = 1.75 Irigoin (σαλπίγγων κτύπος); but cf. also Ath. 8.361e (τυμπάνων κτύπος) and Cyr. *Al. in Isaiam* 1.3.11-12 = *PG* 70.149D (of the lyre).

XIV.1 [50.18-20] **ἐν τῇ... πυθμένα**. Murphy 42 n. 31 suggests that the container is placed inside one of the supporting columns rather than in the base unit, essentially because, in her opinion, it seems almost as if the balls are made to drop out of the bottom of the base (cf. XIV.1 [50.20-1]). There are two problems with this suggestion. First, it openly contradicts Hero's words, and it is not clear why the term βάσις should be taken to mean 'pedestal' (Murphy 23 and 43 n. 38) and not simply 'base'. Second, it is based on a mistaken interpretation of the noun πυθμήν, which in all likelihood refers to the bottom of the ἄγγεϊον rather than to the bottom of the base. Cf. XX.4 [66.11-12]. Perhaps we should imagine a container divided into a number of levels, so that the balls may roll downwards from the top.

G's reading καταβάσει for κάτω βάσει is favoured, albeit tentatively, by Schmidt, who in his app. crit., after comparing XVII.1 [56.11] (κάτω βάσεως), cites Hero, *Mens.* 172.4 (ἢ δὲ κατάβασις τῆς καμάρας). This is rather peculiar, since the latter passage refers to a vault's 'declivity' (LSJ s.v. κατάβασις 4). Neither this nor any other meaning of κατάβασις would be appropriate in the present context. In the *Dioptra* Hero frequently uses the term to denote a 'back-sight' reading (see Schöne 1903: 339 s.v. καταβάσεως), a meaning not registered by LSJ s.v.

XIV.1 [50.21-2] **κλειθρίον... δέη**. On the κλειθρίον mechanism, see note on IX.5 [32.8-9].

AG's ἀνοιγόμενον is certainly genuine. The reading of the *ed. princ.* (ἀπαγόμενον) most likely represents an attempt to correct the corrupt text presented by manuscripts **Pa** (ἀπηγόμενον), **Pd** (ἀποιγόμενον) and **Pf** (ἀπογόμενον). Prou's conjecture ἡνοιγμένον (i.e. ἀνεωγμένον?) is not only

wrong, but also unnecessary, because the slide opens more than once (ὅταν δέη). Prou 171 n. 159 mistakenly reads ἀνοίγμενον for ἀνοιγόμενον both in the manuscripts (i.e. **Pb**, **Pe** and **Pg**) and in the *ed. princ.* (cf. the marginal ἀνοιγ, certainly intended to correct ἀπαγόμενον).

Instead of τῆς σπάρτου, one would rather expect σπάρτου τινός, as this cord has not been previously mentioned. Cf. esp. XIX.4 [62.11-12] σπάρτος τις ἐπισπάσεται τὸ... κλειθρίον, etc. Cf. also XX.2 [64.19-66.1]. But perhaps the presence of the article (overlooked by Baldi 28^r and Murphy 24) points to a now-missing diagram. Similarly, XVI.3 [56.1].

XIV.1 [50.22-3] ὑπόκειται... κυμβάλιον. Obviously, the cymbal, too, has to be positioned at an angle in order to allow the balls to bounce onto it: cf. XIV.2 [52.2].

XIV.2 [52.5] <καὶ>. Schmidt's supplement is needed to coordinate the two consecutive clauses ὥστε... σφαιρία and τὰ μὲν... ἐξῆς.

XIV.2 [52.5-6] τὰ μὲν... ἀνοιχθέντος. This modified version of the device requires a different arrangement of the instruments, each of which must now be positioned in correspondence with one of the container's compartments. Contrast XIV.1 [50.22-3]. According to Prou 171, each χώρα is provided with its own slide. Hero, however, mentions only one slide (κλειθρίου ὁμοίως ἀνοιχθέντος). This presumably means that the partition is placed in such a way as to divide the hole into two equal portions, and that, after the opening of the slide, the two sets of balls are released at the same time rather than sequentially. The implication seems to be that either the hole is made bigger (but cf. XIV.1 [50.20-1] τρήμα... εὐλύτως δυνάμενον δέξασθαι τὰ σφαιρία) or the balls are made smaller.

XV [52.7-54.7] Descending garlands

As a traditional religious symbol (DS 4.1258 s.v. Serta), the garlands accentuate the sacred character of the display. Weighted garlands, woven together into a rectangular wreath (πλέγμα ἐκ στεφάνων τετραγώνων, XV.2), are released from double parapets at the top of the supporting columns. On each side (Prou 171), a hook is turned inwards by means of a cord, allowing a hinged trapdoor to swing open and thus release the wreath (XV.3-4).

XV.1 [52.7] **περιστύλιον**. An extremely rare term, found elsewhere only at *IG* 11².199 A 108 (Delos, 274 BCE); restored at *IG* 4².1.112.32-3 (Epidauros, fourth/third century BCE) and *AJA* 9 (1905) 307.34 (Sinope). Note the *variatio* with XV.2 [52.10] (τετράστυλον). On the need to distinguish between ‘colonnade’ and ‘peristyle’, see Ginouvès (1992: 59 n. 2).

XV.2 [52.9] **γίνεται δὲ οὕτως**. It is unnecessary to add <καὶ τοῦτο> after δέ, as tentatively suggested by Schmidt in his app. crit. In support of this, he compared the expressions γίνεται οὖν καὶ τοῦτο οὕτως (XIII.2 [44.17] and XVII.1 [56.12-13]; cf. also XVI.1 [54.9-10]) and γίνεται δὲ καὶ τοῦτο οὕτως (XIV.1 [50.17-18]). But cf. γίνεται οὖν οὕτως (XII.1 [42.14] and XXV.4 [86.15]).

XV.2 [52.9] **θωράκιον**. See Rance (2009: 96). The term seems to be used to refer both to the individual parapets that run around the top of the (architrave of the) peristyle (here, as at XV.2 [52.10], [52.11] and [52.15], XV.3 [52.18]) and to the structure resulting from the combination of these (XV.2 [52.16], XV.3 [52.19], [52.22] and [54.1] [supplemented], XVI.3 [54.22]). Cf. note on XV.2 [52.14-16]. It also recurs in BOOK TWO, where it refers to the shielded cavity (θωράκιον κοῖλον, XXIII.2 [74.11]) containing the door-closing mechanism (**Fig. 28**); see Schmidt 417 n. 2.

XV.2 [52.10-11] **ἔχον... ἐζηθ**. As shown in **Fig. 21a** (plan view). For a side elevation, see **Fig. 21b** (partly drawing on Schmidt 390 Fig. 95a).

XV.2 [52.12-13] **πλέγμα ἐκ στεφάνων τετραγώνων**. The unusual shape of the στέφανοι is explained by the fact that the wreath is fitted between the (rectangu-

lar) parapets; cf. XV.2 [52.14-15]. The interweaving of rectangular garlands will result in a rectangular wreath; hence there is no reason to suspect τετραγώνων (†τετραγώνων Schmidt) and to adopt the editor's proposed τετράγωνον. In any case, the adjective refers to the shape of the garlands, not to their number ('four', Murphy 25; cf. 'a garland on four sides', Roby 2016: 146). Manuscripts are unanimous (or nearly so) in transmitting πλέγμα (see app. crit. ad loc.). This presumably means that Baldi's πήγμα (45^r n. 28) is due to a misreading or correction of the text.

XV.2 [52.14] εὐαρμόστως. Adverb modifying γενηθέν. It occurs only here in the mechanical corpus, whereas there are no occurrences of the corresponding adjective. Schmidt's suggested εὐαρμόστω is therefore arbitrary.

XV.2 [52.14-16] τοῦτο... θωρακίου. The wreath – or, more precisely, each of its sides – has to be folded together (πτυγέν) in order to fit into the interstitial space between the parapets. For a similar use of πτύσσω, cf. *Spir.* 180.6. It is not clear whether τοῦ θωρακίου refers to the inner or to the outer parapet. Perhaps what is meant is the (ceiling of the) whole structure (inner side: XV.3 [52.21-2]; underside: XVI.3 [54.21-2]; cf. XV.3 [54.1] [supplemented]). This may motivate the contrast between the plural θωράκιοι and the singular θωράκιον. Cf. also XV.3 [52.18-19].

XV.3 [52.17] ἵνα μὴ αὐτόματον καταφέρηται. Cf. the similar expression at XV.3 [52.20-1].

XV.3 [52.19-20] ἐπιπωμαῖσαι τὸ πλέγμα. Before Hero, the verb ἐπιπωμαῖζω ('cover like a lid', 'cap') is attested only twice (Hp. *Loc. Hom.* 47 = 6.344.10 Littré; Arist. *Cael.* 294b15). Apart from the *Automata*, it occurs six times in Hero's corpus, always with reference to the covering, or capping, of holes (*Spir.* 102.5; cf. ἐπιπωμάννυμαι: *Spir.* 132.6; 'présent isolé d'apparence faussement archaïque', Chantraine, *DELG* s.v. πῶμα [1]) and hollow parts (box: *Spir.* 192.19; pipes: *Dioptr.* 196.16, *Spir.* 20.15, 184.2 and 254.2). The only other occurrence of the verb in the treatise, XV.3 [54.1] (passive), appears to refer to the act of covering the underside of the θωράκιον (taken as the whole structure).

See note ad loc. For ἐπίπωμα, cf. *Dioptr.* 300.27 (overlooked by Hammer-Jensen 1910: 502).

XV.3 [52.21-2] ἐκ τῆς... μέρος. The use of the article before the numeral (LSJ s.v. εἰς 1.c) implies an opposition between the inner and the outer side of the parapet. For a more explicit example of this usage, cf. XVI.2 [54.18] (cord end).

XV.3 [52.22] στροφωμάτια εὐλύτα. The term στροφωμάτιον is very rare, occurring only here and twice in the *Pneumatica* (*Spir.* 78.9 and 78.15; cf. Ps.-Hero, *Spir.* 78.26 and 78.31). Elsewhere (*Bel.* 89.1 and 89.2), Hero prefers the base noun to describe a removable hinge (στρόφομα ἀφαιρετόν); see LSJ s.v. I; Marsden (1971: 27). Differently, Hellmann (1992: 391 n. 3), who proposes, albeit hesitantly, another meaning: ‘gaine de goujon’ (‘pin sheath’). Schmidt 79 n. 3 suggested that Hero’s στροφωμάτια were bone hinges, such as those found in Pompeii (on these, see Allison 2006: 30). For εὐλύτος as ‘easily moveable’, cf. *Spir.* 204.9 (pin). In a negative sense: XXVI.3 [92.4-5] λίαν εὐλύτα [sc. κανόνια]... ὥς στρέφεσθαι.

XV.3 [54.1] ὅταν <τὸ θωράκιον> ἐπιπωμασθῇ. I have added <τὸ θωράκιον>, whose omission is easily explained palaeographically (τοῦ θωρακίου... <τὸ θωράκιον>). The subject of ἐπιπωμασθῇ is otherwise ambiguous. In view of ἐπιπωμασαι τὸ πλέγμα one would rather expect the subject to be ‘the wreath’, but not infrequently Hero makes use of the verb with reference to hollow objects comparable to the θωράκιον. See note on XV.3 [52.19-20]. Most translations take τὰ σανίδια (XV.3 [52.20-1]) as the unexpressed subject of the verb (Baldi 28^v; Schmidt 393; Murphy 26). ἐπιπωμάζω, however, does not signify the act of ‘closing’ or ‘shutting’; rather, it signifies the act of ‘covering’ or ‘capping’. In other words, the subject cannot be ‘the boards’, because the verb is used passively. Couture’s ‘clausae remaneant [sc. assulae]’ (259) does not correspond to ὅταν ἐπιπωμασθῇ (omitted in translation), as implied by Murphy 42 n. 34, but to κατέχεται (cf. Baldi’s ‘accioche riserrate rimangono chiuse’).

XV.3 [54.1-2] ἐκ τοῦ... ἀνοίγεσθαι. The ‘other side’ is no doubt the outer side of the parapet; see note on XV.3 [52.21-2]. The hook, or ‘raven’ (κόραξ), must

therefore have been positioned on the same side of the parapet as the hinges, but protruding towards the outside (**Fig. 21b**). In Schmidt 390 Figs. 95a-b, the hook protrudes beyond parapet $\overline{\epsilon\zeta\eta\theta}$ and thus opens outwards. Instead, Hero invites us to imagine the opposite arrangement. The term $\kappa\acute{o}\rho\alpha\zeta$ recurs in *Bel.* 79.10-11 (twice), where it describes the pawl (or 'clicker', $\kappa\alpha\tau\alpha\kappa\lambda\epsilon\acute{\iota}\varsigma$) which engages, on each side of a bow stock, the teeth of a ratchet ($\kappa\acute{o}\rho\alpha\kappa\epsilon\varsigma$ $\sigma\iota\delta\eta\rho\acute{o}\upsilon\varsigma$ in Bito 50.8). See Marsden (1971: 46 n. 14), who suggests that each pawl is straight rather than hooked. On $\kappa\acute{o}\rho\alpha\zeta$ more generally, see Whitehead-Blyth (2004: 88-9), on *Ath. Mech.* 10.12. For $\epsilon\pi\iota\sigma\tau\rho\epsilon\pi\tau\acute{o}\varsigma$ as 'rotating', cf. *Spir.* 134.7-8 ($\sigma\acute{o}\mu\iota\omicron\nu$) and 148.2 ($\tau\rho\omicron\chi\omicron\acute{\iota}$).

It is unnecessary to add $\langle\alpha\upsilon\tau\acute{o}\mu\alpha\tau\alpha\rangle$ after $\mu\acute{\eta}$, as tentatively suggested by Schmidt in his app. crit. The absence of independent movement of the boards has already been emphasised: XV.3 [52.20-1]. A better suggestion would in any case have been $\langle\alpha\upsilon\tau\omicron\mu\acute{\alpha}\tau\omega\varsigma\rangle$. Cf. *Spir.* 174.11-12 $\acute{\omega}\sigma\tau\epsilon\ldots \tau\acute{\alpha}\varsigma$ $\theta\acute{\upsilon}\rho\alpha\varsigma$ $\alpha\upsilon\tau\omicron\mu\acute{\alpha}\tau\omega\varsigma$ $\acute{\alpha}\nu\omicron\acute{\iota}\gamma\epsilon\sigma\theta\alpha\iota$.

XV.4 [54.3-4] $\acute{\epsilon}\kappa$ $\delta\grave{\epsilon}\ldots$ $\pi\epsilon\rho\iota\tau\acute{\iota}\theta\epsilon\tau\alpha\iota$. We may perhaps paraphrase as follows: $\acute{\epsilon}\kappa$ $\delta\grave{\epsilon}$ $\tau\omicron\upsilon$ $\acute{\epsilon}\tau\acute{\epsilon}\rho\omicron\upsilon$ $\mu\acute{\epsilon}\rho\omicron\upsilon\varsigma$ $\acute{\alpha}\gamma\kappa\acute{\upsilon}\lambda\eta$ $\sigma\acute{\pi}\acute{\alpha}\rho\tau\omicron\upsilon$ $\pi\epsilon\rho\iota\tau\acute{\iota}\theta\epsilon\tau\alpha\iota$ $\pi\epsilon\rho\acute{\iota}$ $\tau\omicron\nu$ $\kappa\acute{o}\rho\alpha\kappa\alpha$ ('a loop of cord is wound around the hook from the other side', Murphy 26). The phrase $\acute{\epsilon}\kappa$ $\delta\grave{\epsilon}\ldots$ $\kappa\acute{o}\rho\alpha\kappa\omicron\varsigma$ should be understood in connection with XV.3 [54.1] ($\acute{\epsilon}\kappa$ $\tau\omicron\upsilon$ $\acute{\epsilon}\tau\acute{\epsilon}\rho\omicron\upsilon$ $\mu\acute{\epsilon}\rho\omicron\upsilon\varsigma$), which refers to the outer side of the parapet (see previous note). Hence, the 'other side' corresponds here to the opposite (inner) side, with $\acute{\epsilon}\kappa$ denoting the direction of the cord. Quite differently, Baldi 28^v, who translates the phrase as if it were $\acute{\epsilon}\kappa$ $\mu\acute{\epsilon}\rho\omicron\upsilon\varsigma$ $\tau\iota\nu\acute{o}\varsigma$ $\tau\omicron\upsilon$ $\kappa\acute{o}\rho\alpha\kappa\omicron\varsigma$. Manuscript Paris. gr. 2520 replaces $\pi\epsilon\rho\iota\tau\acute{\iota}\theta\epsilon\tau\alpha\iota$ with $\acute{\epsilon}\pi\iota\tau\acute{\iota}\theta\epsilon\tau\alpha\iota$, an obviously incorrect reading. Cf. esp. XXIII.7 [78.9-10] $\tau\acute{\eta}\nu\ldots$ $\acute{\alpha}\gamma\kappa\acute{\upsilon}\lambda\eta\nu\ldots$ $\pi\epsilon\rho\iota\tau\acute{\iota}\theta\eta\mu\iota$. Cf. also XXIV.6 [84.8-9] and XXVII.4 [98.20-1].

XV.4 [54.4-5] $\tau\alpha\theta\epsilon\acute{\iota}\sigma\eta\varsigma\ldots$ $\acute{\epsilon}\pi\iota\sigma\tau\rho\alpha\phi\acute{\epsilon}\nu\tau\omicron\varsigma$. Note chiasmus.

XV.4 [54.6] $\beta\alpha\rho\acute{\upsilon}\lambda\lambda\iota\alpha$ $\mu\omicron\lambda\iota\beta\acute{\alpha}$. Possibly, conical weights. The term $\beta\alpha\rho\acute{\upsilon}\lambda\lambda\iota\omicron\nu$ is first attested here and in the *Pneumatica* (*Spir.* 180.4 and 218.3; both in the singular), albeit without any reference to shape. It reappears in later sources, such as Synesius (*Ep.* 15.8) and Elias (*in Cat.* 117.10-11; *in Porph.* 21.32). In both

authors, it refers to a cone-shaped weight, be it the balancing weight of a hydrometer (Synesius) or the bob of a plumb-line (Elias); see Lampe (1948). For βαρύλλιον as plumb-bob, cf. also Theon Al. in Ptol. 516.5 (βαρύλλιον μολύβδινον κωνικόν) and 525.2.

XVI [54.8-56.10] Dancing Bacchantes

The Bacchantes, six in number (cf. κατὰ δὲ κίονα... Βάκχη, III.4), are positioned on a rotating ring (ἴνυς) around the shrine (ἐπικείμενται... Βάκχαι, XVI.3; cf. XVI.1). The ring is connected to the main counterweight by means of a drummed axle, which turns together with a pulley (XVI.2-3), increasing the distance rotated. Hero later proposes a similar, although slightly more complicated mechanism to lengthen the distance travelled by the automaton (XVIII.1-2). Schmidt 395 n. 1 does not rule out the possibility that the Bacchantes might also be made to rotate around their own axis, and suggests the use of friction wheels to make this happen (394 Fig. 96a). This clearly goes beyond Hero's intentions (Drachmann 1963a: 197). For a detailed study of the dance of the Bacchantes in Ancient Greece, see Lawler (1927).

XVI.1 [54.8-9] **Τὸ λοιπὸν... καιρόν.** For δὲ δὴ, occurring only here in Hero, see Denniston, *GP* 259. Here δὴ seems to be used to stress the addition made by δέ. Differently, Schmidt 393 ('nun noch') and Murphy 26 ('now'), who take the particle in its proper temporal sense (LSJ s.v.). Both Baldi 29^r and Couture 259 omit translating it.

There is no need to accept Schmidt's suggested χορεύσουσι. The present tense (χορεύουσι) has a generalising force, as in other introductory passages of BOOK ONE: XII.1 [42.11-13], XIII.1 [44.15-16], XV.1 [52.7] and XVII.1 [56.11-12]. One also finds the present in other modal adverbial clauses: V.2 [20.13] (ἡμεῖς δὲ ὑποδείξομεν, ὥς ἔστι, etc.) and IX.6 [32.17-18] (ὥς δὲ δεῖ... νῦν ἐροῦμεν). But cf. the similar passage of XXX.1 [106.4-6].

XVI.1 [54.11-12] **στυλοβάτην... κατὰ τὸ ὕψος.** On στυλοβάτης, see Ginouvès (1992: 15-6); Hellmann (1992: 396). The term is curiously translated as 'columnarium' (= *pulvinar*? see Forcellini s.v. *columnarium* 3) by Couture 259. Murphy 26 has 'foundation', which rather invites us to think of a 'foundation

platform' (see Ginouvès 1992: 11 with n. 29). In his app. crit. Schmidt daringly, if tentatively, suggested emending τὸ ὕψος to κρόταφον. This emendation does not appear to me to be supported by the passages cited by the editor, namely XVI.2 [54.16] and VI.4 [26.1]. The phrase κατὰ τὸ ὕψος here is easily understood as referring to the elevation of the stylobate (see Baldi 45^r n. 29). For a similar use, see, for instance, Bito 55.9 (of a tower).

XVI.1 [54.13-14] *περὶ... ἐζηθκλμν*. The term ἵτις here does not simply denote a 'rim' (cf. *Spir.* 310.9 and 310.11, of cylindrical vessels), as implied by Baldi 29^r ('giro') and Murphy 26 ('felloe'), but a 'Ring' (Schmidt 395; cf. 'ring', Drachmann 1963a: 197) or 'orbiculum' (Couture 259). The latter sense (not registered by LSJ s.v.) draws directly upon the mathematical sense of the word, which Hero (*Geom.* 374.22-4; cf. *Metr.* 68.21-3) defines as the space contained between the circumferences of two concentric circles (the so-called 'annulus'; see *CODM* s.v.). Cf. also *Metr.* 70.4 and 160.1.

Fig. 22a shows three concentric circles, each apparently denoted by four letters (from outside inwards: ἐζηθ, κλμν and αβγδ). As correctly pointed out by Schmidt LVI, the arrangement of the letters is wrong. According to the Teubner editor, two possibilities may be envisaged: (1) the inner circle (αβγδ) corresponds to the stylobate, and hence ἐζηθκλμν are in the wrong place; (2) the inner circle indicates either the space delimited by the shrine's columns or the base of Dionysus, and hence αβγδ (but not ἐζηθκλμν) are in the wrong place. The main problem with either of these possibilities is that the two sets of letters ἐζηθ and κλμν are taken to refer to the circumference of the outer circle (but see Schmidt 394 Fig. 96b), whereas they each denote (and wrongly so) distinct circles. If the outer circle corresponds to the ἵτις (ἐζηθκλμν), as the different ink suggests, κλμν are misplaced too. I have therefore taken the middle circle to refer to the stylobate (αβγδ) and the inner circle to the base of the shrine (**Fig. 22b**). Murphy 25 Fig. 8 has five circles, but it is not always clear which element they correspond to (from outside inwards: 'outer rim of platform' [unlabelled], ἐζηθκλμν, αβγδ, 'roof of shrine' [unlabelled], apex of the cupola [?]).

XVI.2 [54.16-17] *ἐντετορνεύσθω*. This is the only occurrence of the verb with the meaning 'turn on the lathe', and the only one known to LSJ s.v. In other in-

stances, especially late ones (see *DGE* s.v. 2), ἐντορνεύω refers to chiselling and engraving: see, for instance, Apollon. Soph. s.v. λάων; Lucianus, *Adv. Indoctum* 8.19; Ath. *Epit.* 2.2.62.23 Peppink. Once used figuratively (*DGE* s.v. 3): Evagr. Schol. *ad Eulog.* 30 = *PG* 79.1133B (λύπας ἐντορνεύουσιν). Elsewhere Hero prefers the uncompounded form: XXVI.7 [94.20] and [96.2], *Dioptr.* 314.7 (all in the perfect passive); cf. Ph. *Bel.* 77.21 (aorist passive) and Ath. *Mech.* 23.7.

XVI.2 [54.17-18] ἐν ϕ ... {εἰς τὸ βάθος τοῦ σωλήνος}. The words εἰς τὸ βάθος τοῦ σωλήνος were rightly deleted by Schmidt as a repetition from the following line. Murphy 42 n. 35 hesitantly suggests that the phrase is being used for emphasis, apparently without realising that the position of the cord is specified by ἐν ϕ [i.e. σωλήνι]. The verb ἐγκοιμίζω literally means ‘lull to sleep’ (*AP* 7.260.5, Carph.). *LSJ* s.v. cite only the present passage for ἐγκοιμίζω used metaphorically; but cf. Ps.-Chrys. *Hom. in Luc.* 8.5 = *PG* 61.771 τὸν γεωργὸν... τὴν δρεπάνην τῇ σκηνῇ ἐγκοιμίσαντα (*DGE* s.v. 2). Note the stylistic contrast between ἐγκεκοιμίσθω and the following κεκρούσθω.

XVI.2 [54.18] ἥς ἡ μὲν μία ἀρχή. On this use of the article, see note on XV.3 [52.21-2]. For the ‘other end’, cf. XVI.3 [54.21].

XVI.2 [54.19-20] ὥστε μηκέτι ἐκσπᾶσθαι. The expression occurs here and at XXIII.4 [76.8].

XVI.3 [56.1] ἐν τῷ τυμπάνῳ. See note on XIV.1 [50.21-2]. Both Schmidt 395 (‘in einer Welle’) and Murphy 26 (‘on a drum’) have preferred indeterminacy. Baldi 29^r (‘nel Timpano’) has the correct translation. Schmidt’s proposed correction (ἐν τῷ) is awkward, since the Attic form of τινί is never found in Hero.

XVI.3 [56.1-2] ϕ ... στρεφόμενος. Prou 169 maintains that the dance of the Bacchantes is achieved by the same axle that turns the Nike and Dionysus (following his reconstruction; cf. synopsis on XIII.7-8). This is clearly impossible, because Nike’s axle is located not under the parapet, but within the roof of the shrine; cf. note on XIII.3 [46.4-6].

The correct reading must be the adverb εὐλύτως (**AGM**) rather than the adjective εὐλυτος (**T**). The adverb, in fact, is frequently used to describe the smooth rotation of an axle; see note on II.8 [12.6-7]. Murphy 26 seems to misinterpret the meaning of εὐλύτως ('an axle *with enough room* to turn freely'; my emphasis), for she stresses (42 n. 36) that the axle should not rotate independently of the drum. Hence, she suggests that Hero means that the axle is turning on pivots which are fitted into something else. Although pivots are certainly used (cf. XI.8 [40.6-7]), there is no explicit indication in the text of how the axle is made to rotate.

XVI.3 [56.3-5] συμβήσεται οὖν... σπάρτον. A simple transmission system ('einfache Übersetzung', Schmidt LVII; see also **Fig. 23**). Cf. XVIII.2 [58.18-21] (involving a double axle arrangement).

XVI.3 [56.6] δις αὐτὰς δεῖ χορεῦσαι. Cf. IV.2 [18.9-10] (first dance) and IV.3 [18.18-19] (second dance).

XVII.1-2 [56.11-58.2] Concealing the cords

*Hero fills in some gaps, providing information on how to keep the cords orderly and out of sight. A partition divides the σύριγξ into two unequal parts (XVII.1; **Fig. 24**), the larger part containing the millet, the smaller part concealing the cords (XVII.2). A cursory observation on the height of the σύριγξ (ἐπεὶ... μηχανήσασθαι, XVII.2) provides a smooth transition to the discussion of modifications for increasing the range of motion (XVII.3-XIX).*

XVII.1 [56.14] τὸ στόμα τῆς σύριγγος. Here and, with some degree of variation, XVII.1 [56.15] and XIX.1 [60.12]. For στόμα as mouth of a tube, cf. *Spir.* 20.14 and 254.11 (τοῦ στόματος τοῦ συριγγίου). But the term can be used of 'any outlet' or 'entrance': LSJ s.v. II.2 (citing no Heronian instances); especially compare *Spir.* 280.4 (of a flask) with *AP* 6.251.6 ὅλπης... στόματι (Phil.).

XVII.1 [56.15-17] διάφραγμα... στενότατον. For the phrasing, cf. *Spir.* 312.5-6 δύο διαφράγματα τὰ ΕΗ, ΖΘ ἀπολαμβάνοντα χώραν τὴν ΗΘΕΖ (syntactically reversing *Spir.* 306.1-2). The correction στενότατον is Schmidt's. The manu-

script reading στεγνότατον ('watertight') cannot be right because, as the text that follows makes clear, the cords are made to pass through the space delimited by the partition. A similar confusion between στενός and στεγνός occurs at XXVII.1 [98.5] (see app. crit. ad loc.). For ἀπολαμβάνω in the sense of 'fix', 'secure', cf. *DGE* s.v. III.3, citing *ID* 504 A 11 (ἀπολαβὼν χάλκι ἀραρότως), XXIII.5 [76.12] and XXV.4 [86.21] (erroneously cited as 25.5); cf. also XXIII.4 [76.7].

Manuscript diagrams show the partition, along with the mouth of the tube, as seen from above (**Fig. 24a**). So, Baldi 30 unnumbered Fig., but with 'c' (= γ) and 'd' (= δ) inverted. For the sake of clarity ('um der Deutlichkeit willen') Schmidt 397 Fig. 97 with n. 1 preferred a side view (α, γ and ζ are ambiguously placed at the bottom of the tube, whereas δ and ε should not be aligned with β).

XVII.2 [56.18-19] αἱ δὲ... ἀνενεχθήσονται. I follow Schmidt in adopting **M**'s ἀνενεχθήσονται, which must be the genuine reading. Cf. XVII.2 [56.22] (αἱ κάτωθεν ἀναφερόμεναι σπάρτοι) and XIX.1 [60.15]. Haase's emendation ἐνεχθήσονται for **AGT**'s ἀνεχθήσονται is unnecessary.

XVII.2 [56.22-58.1] πολλῶν... ὑπαρχούσης. Note the *variatio* between γινομένων and ὑπαρχούσης and the partial chiasmic arrangement.

Without textual support, Brinkmann's emendation μεγάλης for πολλῆς is implausible both palaeographically and stylistically. The use of the adjective πολὺς to describe the length of journey (πορεία) is common enough and early enough (for instance, Pl. *R.* 614e2, Arist. *Ph.* 220b30, Cleom. *Cael.* 1.4 = 19.37-8 Todd). Cf. XVII.3 [58.4] and XVIII.2 [58.23].

XVII.2 [58.1-2] ἀνάγκη... μηχανήσασθαι. **AGT**'s μὴ has been rightly deleted by Schmidt. **M**'s μὲν would here be out of place. Hero's concern is genuine, given that the height of the σύριγξ determines the distance descended by the counter-weight (Olivieri 1901: 431).

With δεῖ... μηχανήσασθαι cf. XXVI.6 [94.17] δεῖ προμηχανήσασθαι ταῦτα (occurring in identical sentence position). Schmidt 397 misinterprets here: 'Da-her ist noch folgende Hilfsvorrichtung zu machen'. On the other hand, Murphy 26 ('and you must make it so') is too bland. More appropriately, Baldi 30r

(‘bisogna in questo modo ancora aiutarsi con l’ingegno’) and Couture 260 (‘hic quoque arte utendum’).

XVII.3-XVIII [58.3-60.9] Increasing the range (I). Potentially unsuccessful modifications

Three methods are proposed for increasing the distance covered by the automaton (XVII.3-XVIII.2). The first two methods involve either bigger wheels (Hero’s preferred choice) or a smaller axle (XVII.3). Hero does not elaborate, perhaps because of problems arising from changes in the ratio between the axle and the wheels. The third method, applicable also to any other mechanism (καὶ... ἐπιτελεῖσθαι, XVIII.3), is nothing more than a transmission system (**Fig. 25**) in which an added drum amplifies the rotation of the wheel axle (Olivieri 1901: 431; cf. XVI.2-3). This is theoretically possible, but practically unlikely. A heavier, hence bigger, counterweight (cf. XVIII.3) would in fact take up too much space in the σύριγξ. The section closes with an example illustrating how mechanical transmission can be used to increase the range of other movements (i.e. rotation of Dionysus, XVIII.4).

XVII.3 [58.3-4] **δύνανται... παρέχειν**. This obviously depends on the fact that one turn of the axle corresponds to one turn of the wheels. So, for each turn of the axle, the automaton travels a distance equal to the circumference of the wheels: XVII.3 [58.5-7]. The tacit implication is that, if the wheels’ diameter is increased, the height of the base must be increased too.

XVII.3 [58.4-5] **ἢ τὸ τοῦ ἄξονος πάχος ἔλασσον γινόμενον**. Sc. δύναται πολὺ μῆκος παρέχειν. If one reduces the diameter of the axle, the wheels will turn faster, thus increasing the overall distance travelled. This option is not without disadvantages; see following note.

XVII.3 [58.5-8] **ἅπαξ... ποιεῖν**. These lines have been suspected by Schmidt LVI-II of being an interpolation, primarily on the grounds that διὸ... ποιεῖν contradicts the alternative of XVII.3 [58.3-5]. However, as pointed out by Olivieri (1901: 433), there is no contradiction, but rather a continuation of the argument in favour of the enlargement of the wheels. Admittedly, Hero does not bring his

argument to an end nor does he explain why he prefers the former option to the latter. Perhaps we should assume a lacuna after περιφέρεια, in which Hero illustrated the benefits of enlarging the wheels (αὐτούς, indeed, lacks a clear antecedent). Be that as it may, the second option does have some disadvantages. First, a thinner axle means less space for the cord slackenings and, consequently, a lower capacity to programme movements (see McCourt 2012: 196). Second, as the speed of the rotation is increased (see previous note), the automaton becomes more unstable and prone to tipping over.

With τηλικαύτην... περιφέρεια cf. the phrasing at XVIII.2 [58.19-20] τοσοῦτον... περιφέρεια (noted by Schmidt LVII).

XVIII.1 [58.10] τοῦ συμφυοῦς αὐτῷ τροχοῦ. Schmidt's emendation (αὐτῷ) is easy enough, because the wheel rotates together with the axle: XVIII.2 [58.22-3]. Most manuscripts, including **a**, have αὐτοῦ, a reading which probably arose under the influence of the following τροχοῦ.

XVIII.1 [58.15-17] ἐκ δὲ... λείαν. The first part of the sentence is elliptical, since the participle ἐπειληθεῖσα lacks a prepositional complement: either περὶ τὸν ἄξονα (as implied by Baldi's 'che intorno gli è ravolta' [30^v]) or ἐπὶ τὸν ἄξονα (as implied by Schmidt's 'wickle sie darauf' [399]). I am inclined to favour the first interpretation. Cf. XVIII.1 [58.13-14]. Couture 261 ('ad aequipondium... deducatur et alligetur') misconstrues the syntax, associating ἐπειληθεῖσα with ἀποδεδόσθω. Murphy 27 ('Attach the other cord... to the counterweight') omits the participle altogether.

For a similar ellipsis, cf. XXIV.4 [82.13-14].

XVIII.2 [58.18-20] συμβήσεται... περιφέρεια. Hero gives prominence to the rotation of the axle, which both serves as a measure of the emptying of the σύριγξ (τοσοῦτον... περιφέρεια, cf. XVII.3 [58.6-7]) and determines the rotation of the drum (as clearly emerges from the clause that follows; cf. also XVIII.1 [58.12-13]). Schmidt's emendation στραφέντος gives a more precise sense than στρέφοντος. As noted in the editor's app. crit., this emendation has been suggested to him by XVII.3 [58.5-6] (ἅπαξ γὰρ τοῦ ἄξονος στραφέντος; note the *variatio* in the word order). Two manuscripts (**Ea**, **Lb**) have ἀποστραφέντος, which

most probably resulted from the conflation of ἅπαξ (omitted in both manuscripts) and the corrected (or original?) reading στραφέντος.

XVIII.2 [58.20-1] τὴν δὲ... τύμπανον. I adopt Schmidt's proposed emendation ἐπειλείσθαι for **AG**'s ἐπειλήσαι, a reading which, if retained, would require τὴν... σπάρτον to become the direct object and τὸ... τύμπανον the subject: so Murphy 27 ('the drum HΘ... will wind the cord from axle AB once'). This can hardly be correct, given the correlation with the preceding clause (ὀλίγον μὲν μέρος... τὴν δὲ... σπάρτον). Schmidt (app. crit. ad loc.) also tentatively suggested adding <εἰς> after ἐπειλείσθαι, and indeed, despite his Greek text (ἐπειλήσαι), translated accordingly ('die Schnur... sich einmal auf die Welle ηθ wickelt', 399). On the basis of XVI.3 [56.3-5] (συμβήσεται... ἐπειλείσθαι ἐπὶ τὸ... τύμπανον τὴν... σπάρτον), I prefer to add <ἐπὶ>, which could have easily been omitted (ἐπειλείσθαι <ἐπὶ>). Some manuscripts (**Ad**, **Ac**, Barb. gr. 261 and **Ld**) have the incorrect reading ἀπειλήσαι, which implies that the drum rotates in the opposite direction. Baldi 30^v-31^r appears to retain ἐπειλήσαι, but mistranslates it: 'la corda... circonda una volta sola il Timpano'.

XVIII.2 [58.23-4] πολὺ μῆκος τῆς πορείας γίνεσθαι. An existential use of γίνομαι. So Schmidt 399 ('ergiebt sich eine bedeutende Länge der Fahrt'). In a copulative sense: Baldi 31^r ('sia *molto* lungo il viaggio', my emphasis) and Couture 261 ('sit longius iter'). Murphy 27 translates much more freely: 'the motion will cover a longer distance'.

XVIII.3 [60.1-2] μείζονος... κινεῖσθαι. Hero relies here on the allegedly Archimedean principle of concentric circles (*Mech.* 2.7; cf. Papp. 1068.19-23; Drachmann 1963a: 61-3; Knorr 1982: 90-2), by which, following in the footsteps of Philo's lost book on levers (*Μοχλικά*, cf. Ph. *Bel.* 59.11-12) and Ps.-Aristotle's *Mechanica*, he elsewhere (*Mech.* 2.8-20; cf. *Mech.* 2.1) explains, or attempts to explain, how each of the five powers (but particularly the windlass and the lever; see following note) can move a large weight with a small force (Schiefsky 2008: 22-32; Laird 2015: 290-301, *contra*, argues that only the windlass and the lever are reduced to concentric circles, and that the pulley, the wedge, and the screw are explained by another principle, which he calls the prin-

ciple of dividing and sharing the load). The reference to bigger and smaller circles (not ‘wheels’, Murphy 27) is a reference to the drum $\overline{\eta\theta}$ and the axle $\overline{\epsilon\zeta}$ (see Schmidt 399 n. 2; the generalising plural also appears twice at XVIII.4 [60.7-8]). Unlike in the case of concentric circles, the moving power is applied (by means of a pulley) to the circumference of the smaller circle. Since the ratio between force and weight is the inverse of the ratio of the distances from the centre (*Mech.* 2.7; cf. [Arist.] *Mech.* 850b1-2; Schmidt 399-401 n. 3), a greater force is required to turn the drum, thereby overcoming the resistance of the wheel and axle assembly. On the basis of *Dioptr.* 312.20-22, where the principle is used to account for the operation of the *baroulcos* or ‘weightlifter’ (see the discussion in Berryman 2009: 136), Schmidt (app. crit. ad loc.) tentatively suggested adding <ὅταν περὶ τὸ αὐτὸ κέντρον κυλίωνται> after κινεῖσθαι. This supplement is unnecessary, because it is obvious that $\overline{\eta\theta}$ and $\overline{\epsilon\zeta}$ rotate about a common axis passing through their centre: that is to say, it is obvious that they can be reduced to concentric circles.

Perhaps emend προσδεῖται to προσδεῖ (Schmidt dub. in app. crit.). The impersonal middle προσδεῖται is significantly less frequent than its active counterpart: LSJ s.v. προσδέω (B) II.2 (not noting the present passage; add Ps.-Aristeas, *Ep. ad Philocr.* 11.5). But see KG 1.396 (Schmidt in his app. crit. refers to ‘Kühner Gr. II 255’, but this seems erroneous, for neither the first nor the second nor the third edition contains relevant information on that page).

XVIII.3 [60.3] ταῦτα... ἔστι. Or, perhaps better, ‘by means of the principles of leverage’ (μοχλικῶν, Brinkmann), as understood by Baldi 31^r (‘ragioni del vette’) and, more drastically, Couture 261 (‘tractatum de vecte’). By all appearances, Hero intends to clarify his reference to bigger and smaller circles. For the reduction of the lever to the principle of concentric circles and, ultimately, to the balance, cf. Hero, *Mech.* 2.8 (seemingly drawing on [Arist.] *Mech.* 850a30-850b9). When reduced to concentric circles, the arms of the lever correspond to the distances from the centre (i.e. here the radii of the drum $\overline{\eta\theta}$ and the axle $\overline{\epsilon\zeta}$); see Schmidt LVII, 399-401 n. 3 and, more generally, previous note. The reading of **AGT**, μοχλίων, is certainly better than **M**’s κοχλίων (Baldi 45^r n. 30 already corrected the latter reading, which he claimed to have found in his exemplar). While the screw bears little (Shiefsky 2008: 28, 30-1) or no (Laird 2015: 300)

similarity to concentric circles, *μοχλίων* fits much better into Hero's explanatory agenda for mechanical phenomena; see Schiefsky (2008: 23), who finds a parallel between Hero, *Mech.* 2.1 and [Arist.] *Mech.* 848a11-14 τὰ μὲν οὖν περὶ τὸν ζυγὸν γινόμενα εἰς τὸν κύκλον ἀνάγεται, τὰ δὲ περὶ τὸν μοχλὸν εἰς τὸν ζυγόν, **τὰ δ' ἄλλα πάντα σχεδὸν** τὰ περὶ τὰς κινήσεις τὰς μηχανικὰς εἰς τὸν μοχλόν.

It is unnecessary either to transpose δὴ after γὰρ (Schmidt dub. in app. crit.) or to emend it to δῆλὰ (Brinkmann). Cf. *Bel.* 102.8-9 οὐ γὰρ κατασκευάζεται πάμπολλα δὴ πρὸς τὰς κατεπειγούσας χρεῖας. For γὰρ... δῆ (hardly characteristic of Hero), see Denniston, *GP* 244. In the manuscripts **Ab**, **Ac** and **Bb**, a space of varying size is left blank between *κοχλίων* and δὴ (δὲ **Bb**). This is probably just a mistake, for in two cases the scribe drew a line between the words either across (**Ac**) or below (**Ab**) the space.

XVIII.3 [60.3-5] καὶ... ἐπιτελεῖσθαι. If Hero is keeping up the analogy with concentric circles, as it seems, then the μικρὰ διαστήματα are 'small radii' (Murphy 27; cf. LSJ s.v. διάστημα I.1.b and Hero, *Deff.* 27), and not simply 'short distances' ('kleine Entfernungen', Schmidt 401) or, even worse, 'small lengths' of cord ('piccioli spatij, cioè di corda', Baldi 31'). μεγάλας οὔσας clearly refers to the duration of movements (Schmidt 401); Murphy 27 ambiguously translates 'on a large scale'.

XVIII.4 [60.6-9] ἐὰν γὰρ... ὑπεδείξαμεν. This passage has been unjustly suspected (Schmidt LVII-III; endorsed by Brinkmann and Olivieri 1901: 433) as an interpolation. Schmidt's main reasons are as follows. First, the apparatus for the rotation of Dionysus (XIII.7-9 [48.13-50.14]) is an unsuitable example of mechanical transmission, in that Dionysus rotates only 180 degrees (twice); the dance of the Bacchantes would have been a much more fitting example (cf. XVI.3 [54.21-56.6]). Second, μείζονας κύκλους presupposes a repeated transmission (i.e. a higher number of rotations), and the singular τῷ μείζονι is awkward. Third, the phrase ἡ δὲ εἰς τὴν λείαν, unaccompanied as it is either by ἀποδιδομένη (as at XIX.3 [62.6]) or ἀποδεδομένη (as at XXVI.8 [96.9]), is harsh. Fourth, ἐὰν γάρ (as used here?) is otherwise unfamiliar to Hero. As to the first point, it is true that, unlike the Bacchantes' dance, the mechanism for turning Dionysus does not involve a transmission system which lengthens the dis-

tance rotated. However, Hero might be developing, albeit still in an embryonic form, an alternate system that allows Dionysus (and the Nike?) to complete one or more full rotations either before or after (or both before and after) the second altar has lit. Brinkmann's deletion of τοῦ Διονύσου (disliked by Olivieri) is, therefore, not only unnecessary but also undesirable. As far as μείζονας κύκλους is concerned, the plural should not be taken as indicating a repeated transmission but rather as a generalising plural (cf. ἐλάσσονας ἄξονας) denoting a single drum; cf. XVIII.3 [60.1-2] with note ad loc. Thus, τῷ μείζονι could be a mere slip of the pen for τοῖς μείζουσι. If so, it requires neither to be emended to the plural (as proposed by Schmidt in the *Anmerkungen*; but see already Baldi 31^r) nor to be supplemented by <κύκλω> (as hesitantly proposed by Schmidt in his app. crit.). The noun phrase ἡ δὲ εἰς τὴν λείαν is not necessarily incomplete. We do find comparable expressions for cords coming from (ἐκ) a certain direction (XII.4 [44.8-9] and XVI.3 [56.5]) or passing around (περί) a certain instrument (XVI.3 [56.3-4]). In any case, it is clear that there are two cords – one going from Dionysus' pipe (ὄργανον) to the drum and another going from the drum's axle to the counterweight (in analogy with XVIII.1 [58.12-17]; cf. **Figs. 25a-b**) – rather than only one, as wanted by Murphy 27 ('for if the cord moving the apparatus of Dionysus is wound around greater circles, *it must* then go, etc.', my emphasis). Last but not least, ἐὰν γάρ is not at all uncommon in Hero: VIII.1 [28.4], *Deff.* 83.1, *Dioptr.* 252.11 and 272.21, *Mech. Frag.* 2.35 = Papp. 1034.14, *Metr.* 6.14 (supplemented), 74.6, 74.26, 86.4, 94.1-2, 138.20 and *Spir.* 4.17; cf. *Mech. Frag.* 3.1 = Papp. 1130.18-19 (ἐὰν μὲν γὰρ... ἐὰν δέ). Unlike these other passages, here ἐὰν γάρ ('wenn z.B.', Schmidt 401; my emphasis) introduces a protasis without apodosis, where γάρ establishes a logical connection with the previous sentence; for comparable examples with combinations such as ὥς γάρ, ἐπεὶ γάρ and, more relevantly, εἰ γάρ, see Vahlen (1885: 128-130), already quoted by Schmidt in his app. crit. ('Vahlen Aristot. poet. p. 128³'). So, while Schmidt's suggested deletion of γὰρ disrupts the logical coherence of the text, the apodosis can be easily supplied from the context ('this happens', where the pronoun more correctly refers to the idea in the previous sentence rather than to XVIII.1-2 [58.9-23], as in Baldi 31^r and Couture 261). On incomplete conditional sentences, see generally Goodwin (1889: 179 n. 482) and KG 2.484-5.

XIX [60.10-62.20] Increasing the range (II). Two-counterweight system
Hero provides only a sketchy ('summarisch', Schmidt LVIII; cf. Schmidt 1903: 278) account of his two-counterweight system. The σύριγξ, and not the whole case ('cassettone a due spartimenti', Olivieri 1901: 432), is divided into two parts (Fig. 26), each containing a counterweight (XIX.1). One counterweight brings about forward and backward motion, the other all the remaining movements (XIX.2; cf. XIX.3-5). A more complex mechanism (involving, among other things, a greater number of cords) has been devised by Querfurth (Schmidt LVIII-IX with Figs. 99b and 99c; unduly criticised by Olivieri 1901: 431). For further discussion, including rebuttal of Olivieri's view that the chapter is interpolated, cf. Introduction, pp. cxiii-cxv.

XIX.1 [60.10] ἐπιπορεία. The term occurs only here and at XIX.2 [60.17] in the whole corpus of Greek literature. For ἐπιπορεύομαι, cf. XIX.4 [62.11]. The change from πορεία/πορεύομαι is probably only stylistic.

XIX.1 [60.11] αἱ ἔξωθεν <τῆς πορείας> κινήσεις. Schmidt's supplement is surely right. Cf. II.8 [12.3-4], XII.1 [42.10-11] and XVIII.3 [60.3-4]. The words τῆς πορείας may easily have dropped out owing to the proximity of ἐπιπορεία and ἀποπορεία.

XIX.1 [60.12-14] ἔστω γὰρ... εὐθείας. Note the *figura etymologica* with the noun διάφραγμα, which is frequently used by Hero in the *Pneumatica*: see, for instance, *Spir.* 102.24-104.1, 112.16-17 and 116.14-118.1 (plural). The verb διαφράσσομαι, occurring only here in the *Automata*, is generally employed by Hero (only in the *Pneumatica*) to refer to horizontal partitioning; but cf. *Spir.* 152.9-13 (vertical partitioning). Just as in the case of the single partitioning (XVII.1 [56.15-16]), manuscript diagrams show a plan view of the σύριγξ (Fig. 26a). So Baldi 31^v unnumbered Fig. and Schmidt 402 Fig. 99a. For a side view, see Schmidt LVIII and 403 Fig. 99b (including more details than are warranted by the text).

XIX.1 [60.14-16] ὥστε... λείας. Perhaps we should emend κάτω to κάτωθεν (cf. XVII.2 [56.19] and [56.22]). The omission of -θεν might have arisen from over-

sight (εν being often abbreviated as L or \angle and written above the line: Allen 1889: 14 and Pl. IV; Gardthausen 1913: 337). Translators have been inattentive here, for they either rendered the adverb as if it were κάτωθεν ('da basso', Baldi 31^r; 'ab imo', Couture 261; 'von unten', Schmidt 401) or omitted it altogether (Murphy 27). The plural τὰς λείας is curiously translated by Murphy 27 as 'the counterweight'.

XIX.2 [60.20-62.1] ἐν τῇ ἡθγδ. Here, too, there must have been millet seeds. If Hero does not specify, it is probably because he wants to avoid repetition.

XIX.2 [62.1-2] ἑκατέρω... παράγεσθαι. Hole $\bar{\kappa}$'s slide is connected to three cords (one that opens it, another one that closes it, and yet another one that opens it), whereas hole $\bar{\lambda}$'s slide has only one cord attached (it need not be closed once the millet has run out). Murphy 43 n. 42 makes (somewhat tentatively) two points. First, the opening of each slide is controlled reciprocally by either counterweight. Second, $\bar{\kappa}$'s slide is closed either at the same time $\bar{\lambda}$ is opened (by means of one and the same cord) or after $\bar{\lambda}$ is opened, by means of a cord pulled tight under the impulse of the second counterweight. The first point seems right, except that $\bar{\kappa}$'s slide is first opened manually: XIX.3 [62.3-4]; cf. IX.5 [32.10-12]. As for the second point, $\bar{\lambda}$'s slide is opened during forward motion (XIX.4 [62.11-12]), which means that $\bar{\kappa}$ must be closed at a later time. It is not entirely clear how $\bar{\kappa}$'s slide is closed, but XIX.4 [62.14-15] strongly suggests that it is pulled shut by the cord connected to the second counterweight (or, possibly, by another cord branching off it); see further note on XIX.4 [62.15].

On παράγω, see note on XII.2 [42.17-18].

XIX.3 [62.3] παράξομεν. This is no doubt the correct reading, and is supported by all manuscripts. Cf. XIX.2 [62.2]. In the margin of manuscript **F** we find the tentative emendation προσάξομεν ('bring to' or 'upon'), which does not fit into the present context.

XIX.3 [62.4-7] ἵνα... χαλασμάτιον. Cf. IX.6 [32.14-15]. The addition of μὴ (endorsed by Murphy 43 n. 41) is Schmidt's, and has been anticipated by Baldi 31^r ('non'). The pleonasm ὁρμὴν λαβὼν... κινηθῇ is emphatic and is unparalleled else-

where. But cf. Ph. *Quod deterius potiori insidiari soleat* 127.5 ὁ νοῦς ἐξαναστὰς... ὁρμὴν λάβη ἢ κινηθεὶς ἔνδοθεν, etc. (with a *variatio*). The preposition ὑπέρ (rightly deleted by Schmidt) seems to be an intrusive gloss explaining the position of the counterweight. Baldi 31^r ('le carrucole di sopra') translates τροχῶν as if it were τροχίλων (Couture 262 follows suit, but changes the plural to the singular). Such rendering is best explained as an attempt to make sense of the corrupt reading ὑπερτροχῶν, transmitted in **M** and other manuscripts.

XIX.3 [62.7-9] χρόνος... χάλασμα. The equivalence between the periods of (apparent) inactivity of the automaton and the length of cord slacks is first formulated here. This formulation, however, is foreshadowed in the idea that the cord slacks should be made proportional to the distances travelled by the automaton: X.3 [34.16-17] and XI.5 [38.4-5]; cf. XI.5 [38.1-3] with note ad loc.

For ἀποστάντων ἡμῶν, cf. IV.1 [18.2] (supplemented).

XIX.4 [62.11] ἐπιπορευομένου. Cf. note on XIX.1 [60.10]. **AG**'s reading is preferable to **M**'s πορευομένου. The omission of ἐπι- probably arose because of its similarity with the preceding ἔτι. Cf. also XIX.4 [62.13] (πορευομένου).

XIX.4 [62.11-12] ἐπισπάσεται... αὐτό. For the phrasing, cf. XIX.5 [62.18-19].

XIX.4 [62.15] ἦτις... κλειθρίον. I take the verb ἐπισπάσεται to mean, as both Baldi 31^v ('si ritirerà') and Couture 262 ('retrahetur') did (note passive sense), that κ's slide is closed, rather than opened ('will... open', Murphy 27), by the cord (Schmidt 403, more neutrally, has 'zieht... an', but he clearly believes that this cord causes the slide to close: see Schmidt LX and 403 n. 1). κ's slide is opened twice, once in order to make the automaton move forward (XIX.3 [62.3-4] παράξομεν τὸ... κλειθρίον, ὥστε ἀνοιχθῆναι), and once to make it come back (XIX.5 [62.18-19] ἑτέρα σπάρτος ἐπισπάσεται τὸ... κλειθρίον καὶ ἀνοίξει αὐτό). Its second opening, therefore, occurs after, not during, the completion of the other movements (cf. XIX.5 [62.16-18]). Its closure, on the other hand, brings the automaton to a halt before the sequence of movements begins: XIX.5 [62.16] (καὶ οὕτως στήσεται τὸ πλινθίον). Perhaps, then, we should assume that

the verb κλείσει has dropped out after καὶ (ἐπισπάσεται καὶ <κλείσει> τὸ... κλειθρίον). Cf. *Spir.* 182.5-6 βάρος... ἐπισπάσεται καὶ κλείσει τὰς θύρας.

XIX.5 [62.18-19] **ἐτέρα... αὐτό.** There is no doubt that Hero refers here to a different cord (**ἐτέρα** σπάρτος) from the one used for closing $\bar{\kappa}$'s slide. So, Schmidt 405 with n. 1 ('eine andere Schnur'). Both Baldi 31^v ('l'altra corda, che è attaccata al chiusoio k') and Murphy 27 ('the other cord') use the definite article instead. Baldi is probably referring, albeit erroneously, to the cord by which $\bar{\kappa}$'s slide is initially opened (not explicitly mentioned in the present context, and pulled *manually*; see note on XIX.2 [62.1-2]). Murphy, on the other hand, seems to be referring to the cord used for closing $\bar{\kappa}$'s slide (XIX.4 [62.14]), since she recognises here that the latter is opened by the action of the second counterweight (Murphy 43 n. 42). This would explain why she misinterprets ἐπισπάσεται (XIX.4 [62.15]) as referring to the opening of $\bar{\kappa}$'s slide; see previous note.

APPENDIX 1. CONCORDANCE OF EDITIONS

The following is a concordance between the present edition and the editions by Thévenot, Prou and Schmidt. Thévenot is cited by page and line number. References to Prou and Schmidt are by chapter, section, page and line number (given in square brackets). If the section is omitted, the reference is to the entire chapter. Prou's sections are indicated by Greek numerals.

Grillo	Thévenot	Prou	Schmidt
I [2.3-6.8]	243.10-244.38	-	I [338.3-342.10]
II [6.9-14.16]	244.39-246.25	-	II [342.11-348.25]
III [14.17-16.22]	246.26-247.2	-	III [350.1-352.4]
IV [18.1-20.7]	247.2-31	-	IV [352.5-354.9]
V [20.8-22.20]	247.32-248.14	-	V [354.10-358.5]
VI [22.21 -26.5]	248.15-249.12	-	VI [358.6-362.3]
VII [26.6-28.3]	249.13-250.2	-	VII [362.4-364.7]
VIII [28.4-30.2]	250.3-26	-	VIII [364.8-29]
IX [30.3-32.18]	250.27-251.39	-	IX-X.1 [366.1-368.26]
X [32.19-34.24]	251.39-252.20	-	X.1-4 [368.27-372.16]
XI [36.1-42.8]	252.21-255.11	-	XI [372.17-380.11]
XII [42.9-44.14]	255.12-256.7	-	XII [380.12-382.19]
XIII [44.15-50.15]	256.8-257.29	-	XIII [382.20-388.15]
XIV [50.16-52.6]	257.30-258.17	-	XIV [388.16-390.6]
XV [52.7-54.7]	258.18-259.11	-	XV [390.7-392.22]
XVI [54.8-56.10]	259.12-260.7	-	XVI [392.23-396.7]

XVII [56.11-58.8]	260.8-29	-	XVII [396.8-398.2]
XVIII [58.9-60.9]	260.30-261.25	-	XVIII [398.3-400.13]
XIX [60.10-62.20]	261.26-262.29	-	XIX [400.14-404.3]
XX [64.2-68.4]	263.2-264.2	I [206.7-210.3]	XX-XXI.1 [404.5-410.8]
XXI [68.5-70.3]	264.3-23	II. $\bar{\alpha}$ - $\bar{\gamma}$ [210.5-212.3]	XXI.1-2 [410.8-412.2]
XXII [70.4-74.4]	264.24-265.23, 266.28-9	II. $\bar{\delta}$ -III [212.4-215.8], V. $\bar{\alpha}$ [220.4]	XXII [412.3-414.23]
XXIII [74.5-78.19]	266.29-268.18	V. $\bar{\beta}$ - $\bar{\varsigma}$ [220.5-225.3]	XXIII [416.1-420.21]
XXIV [80.1-84.10]	265.23-266.23	IV [216.2-12]	XXIV [422.1-426.3]
XXV [84.11-90.5]	266.24-6, 268.19-269.14	V. $\bar{\alpha}$ [220.2-3], VI. $\bar{\alpha}$ - $\bar{\gamma}$ [225.5-229.1]	XXV [426.4-430.22]
XXVI [90.6-96.15]	269.14-270.32	VI. $\bar{\gamma}$ -VII. $\bar{\epsilon}$ [229.1-235.11]	XXVI [430.23-436.19]
XXVII [98.1-100.4]	271.1-25	VII. $\bar{\epsilon}$ -VIII [235.12-238.4]	XXVII [438.1-440.3]
XXVIII [100.5-104.13]	271.26-272.46	IX [238.6-243.2]	XXVIII [440.4-446.11]
XXIX [104.14-106.3]	272.47-273.9	X. $\bar{\alpha}$ - $\bar{\beta}$ [243.4-244.3]	XXIX [446.12-25]
XXX [106.4-110.15]	273.9-274.32	X. $\bar{\gamma}$ -XI [244.4-248.6]	XXX [448.1-452.12]

APPENDIX 2. *ADDENDA ET CORRIGENDA* TO SCHMIDT

The following table lists the errors, oversights and omissions made by Schmidt in his apparatus criticus and not noted in the list of *addenda et corrigenda* appended to the first volume of his edition ('Berichtigungen', pp. 513-14). All references are made to the page and line number in Schmidt's edition. The *consensus codicum* **a** here comprises only **A**, **G** and **T**.

<i>App. crit. ad p.</i>	<i>ERRATA</i>	<i>ADDENDA ET CORRIGENDA</i>
340.16	σκερπανίζοντα a	a <i>in</i> AG <i>corrige</i> , <i>adde</i> σκερπανίζοντα T
340.17	ἀφύραις ex ἀφύρες corr. G	ex ἀφύρες corr. <i>dele</i>
342.17	ἀπωθώσαντες T	ἀπωθώσαντες <i>in</i> ἀποθώσαντες <i>corrige</i>
344.7	πάντα AG : πάντη M : πάντι T : del. R. Schoene	πάντα AG : πάντη M : πάντι T <i>refer ad</i> 344.7 πάντα (<i>secunda iteratione</i>)
344.21	παρεντεταμένην AG	A <i>dele</i> , <i>adde</i> παρεντεταμένην A ^{pc} : παρεντατταμένην A ^{ac}
344.21	οὐδενὶ ἰ δεῖ (οὐδενὶ ex οὐδενὸς corr.) G	ἰ δεῖ <i>in</i> ἰδεῖ <i>corrige</i>
354.11	ἀποπορείας T	ἀποπορείας <i>in</i> εὐποπορείας <i>corrige</i>
354.15 (<i>vide etiam</i> Supplementum 111)	ευθείας A ₁	ευθείας <i>in</i> ἐπευθείας <i>corrige</i>
356.11	ἐπειλείσθω T : ἐπειλείσθη A (?), G	(?) <i>dele</i> , A <i>ante</i> T <i>transpone</i>
358.6	ἡ M : εἰ a	<i>refer ad</i> 358.7 ἡ
362.3	περικειμένη Leid. Vulc. 4 :	περικειμένη <i>dele</i> , Leid. Vulc.

	περικειμένην a	<i>4 post a transpone</i>
376.4	ἐπειλήσεων M	ἐπειλήσεων <i>in</i> ἐπιλείσεων <i>corrigere</i>
376.14-16	ὅθεν ... χοινικίδι G	ὅθεν <i>in</i> ἠρξάμεθα <i>corrigere</i> (<i>sed vide Supplementum</i> 113)
376.15	ἐν a	a <i>in</i> AT <i>corrigere</i>
382.2	ἀποδοδομένον G : ἀποδοδομένων A (?)	(?) <i>dele</i> , A <i>ante</i> G <i>transpone</i>
382.2	ἐντὸ T	ἐντὸ <i>in</i> ἐν τὸ <i>corrigere</i>
384.1	ἀνατείνοντα Amg. GT ₂ : ἀνατείνονται A ₁ T ₁	G <i>inter</i> A ₁ <i>et</i> T ₁ <i>transpone</i>
384.4	τρύπημα τι T	τρύπημα τι <i>in</i> τρύπηματι <i>corrigere</i>
384.8	ὁ om. G	<i>refer ad</i> 384.7 ὁ
388.14	κρυπτέσθω M : κριπτέσθω a	a <i>in</i> AG ^{ac} T <i>corrigere</i> , <i>adde</i> G ^{pc} <i>post</i> M
388.23	δέη AG (ex δεήσει corr. A)	δεήσει <i>in</i> δεήση <i>corrigere</i>
400.10	ἀποδίδεται codd.	codd. <i>in</i> AGT <i>corrigere</i> (<i>alii</i> <i>codices</i> ἀποδίδεται <i>habent</i> , <i>alii</i> ἀποδίδεται)
404.11	βουλόμεθα AT : βουλόμεθα G	βουλόμεθα <i>dele</i> , G <i>inter</i> A <i>et</i> T <i>transpone</i>
410.5	παρατίθεται codd.	codd. <i>in</i> AG ^{pcsl} <i>corrigere</i> (<i>alii</i> <i>codices</i> παρατίθεται <i>habent</i> , <i>alii</i> παρατίθεται)
410.20	ἢ AT : καὶ G	καὶ G <i>dele</i> , AT <i>in</i> a <i>corrigere</i>
414.8	αἱ νῆες om. T ₁ : add. T ₂	<i>refer ad</i> 414.7 αἱ νῆες
414.9	παρεκολύμβων δὲ a	a <i>in</i> A ^{pc} M <i>corrigere</i> , <i>adde</i> παρεκολύμβον δὲ A ^{ac} G
416.2	τὸν A : τὴν GT	G <i>post</i> A <i>transpone</i>
420.1	αἱ μέντοι M	αἱ μέντοι <i>in</i> καὶ αἱ μέντοι

		<i>corrigere</i>
422.1	Καὶ ταῦτα μὲν οὖν inserit R. Schoene l.l. p. 74	οὖν <i>dele</i> , <i>adde</i> Καὶ ταῦτα μὲν οὖν inserui
424.21	αὐτῷ scripsi : αὐτῷ a	scripsi <i>in</i> Prou <i>corrigere</i>
426.4	f. μὲν <οὖν>	οὖν <i>iam</i> Prou (<i>sed verbum non inventum est in codicibus a Prou adhibitis</i>)
428.7-8	ὑπὸ κάτω a : correxi	ὑποκάτω <i>iam</i> Prou (<i>verbum ex Pd, Pe, Pg et Ph depromptum, sed non notatur</i>)
430.16	οὕτως G : οὕτω AT	G <i>in</i> G ^{ac} <i>corrigere</i> , <i>inter</i> A <i>et</i> T <i>adde</i> G ^{pc}
430.23	οὖν om. A	<i>post</i> A <i>adde</i> G
430.24	μηδὲν ἐμφαίνεσθαι Prou	Prou <i>in</i> M. Egger <i>corrigere</i> (<i>vide</i> Prou 230 n. a)
432.10	προκείμενα GM	M <i>dele</i> , <i>adde</i> : προσκείμενα M
432.22	ὑποστρέφοντας Prou	ὑποστρέφοντας <i>in</i> ὑποστρεφόντας <i>corrigere</i>
434.19	οὕτως G	οὕτως G <i>in</i> οὕτως G ^{ac} : οὕτος G ^{pc} <i>corrigere</i>
436.1	ἔστω γὰρ GT ₂ : om. AT ₁	A <i>dele</i> (γὰρ <i>tantum omittit</i> A)
438.11	ἔστω <δὲ> εἰς Prou	<δὲ> <i>dele</i>
440.15	καὶ om. G	om. <i>dele</i> , καὶ <i>in</i> ἐκ <i>corrigere</i>
442.1	ἐπὶ* μὴ κειμένη ed. Paris., ‘*f. ῆ’ in margine	ῆ <i>in</i> ῆ <i>corrigere</i>
442.13	κιβω ^{τρ/} (= κιβώτρου?) AG	κιβώτρου <i>in</i> κιβωτηρίου vel κιβωτέρου <i>corrigere</i> (<i>de superscripto compendio τρ vide</i> Bast 1811: 792)
448.2	ὅ τε Brinkm. et Prou : ὅτε a	a <i>in</i> GM <i>corrigere</i> , <i>ante</i> Brinkm. <i>adde</i> A

450.7	ἀπογράφεται Prou	ἀπογράφεται <i>in</i> ἀπογράφεταιί <i>corrige</i>
452.10	f. τοιοῦτων	<i>videtur referendum ad</i> 452.11 τούτων

APPENDIX 3. *STEMMATA CODICVM*

Stemma 1

IV s.

Ω

α

β

XIII s.

A

δ

η

θ

ι

ζ

XV s.

ν

τ

XVI s.

Ea

Lb

Aa

Bc

O

ω

Pb

Vd

XVII s.

F

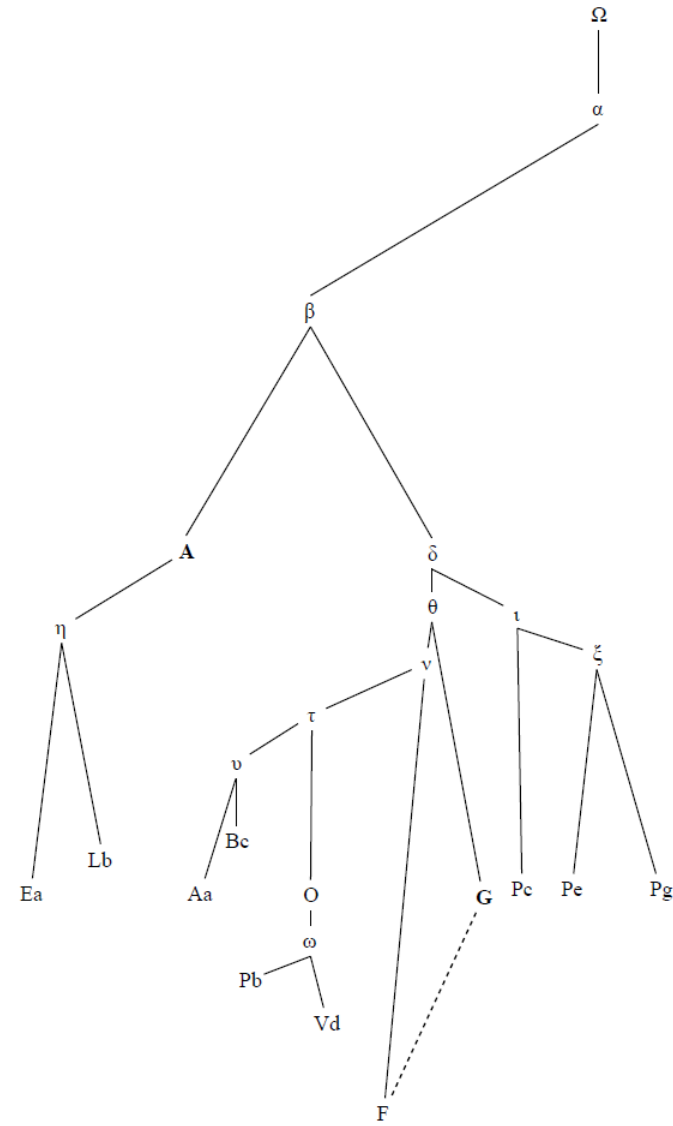
XVIII s.

G

Pc

Pe

Pg



Stemma 2

IV s.

Ω

α

γ

XIII s.

ε

ζ

XV s.

κ

λ

XVI s.

Bb

\omicron

π

χ

ψ

ρ

ϕ

$\alpha\alpha$

$\beta\beta$

Lc

Ld

Ac

Ad

Ph

M

Tb

Mb

Pd

Ta

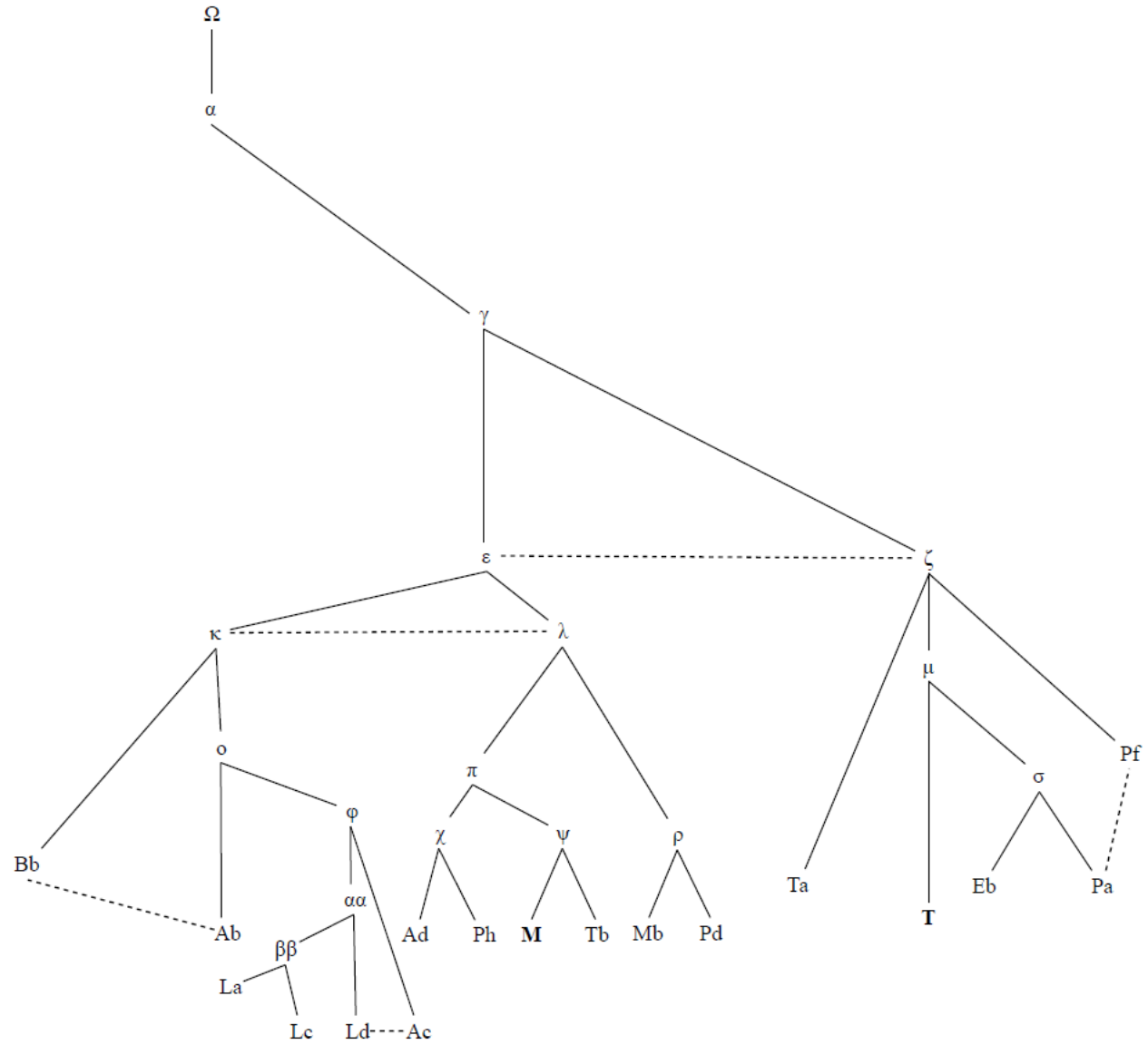
T

Eb

Pa

Pf

XVII s.

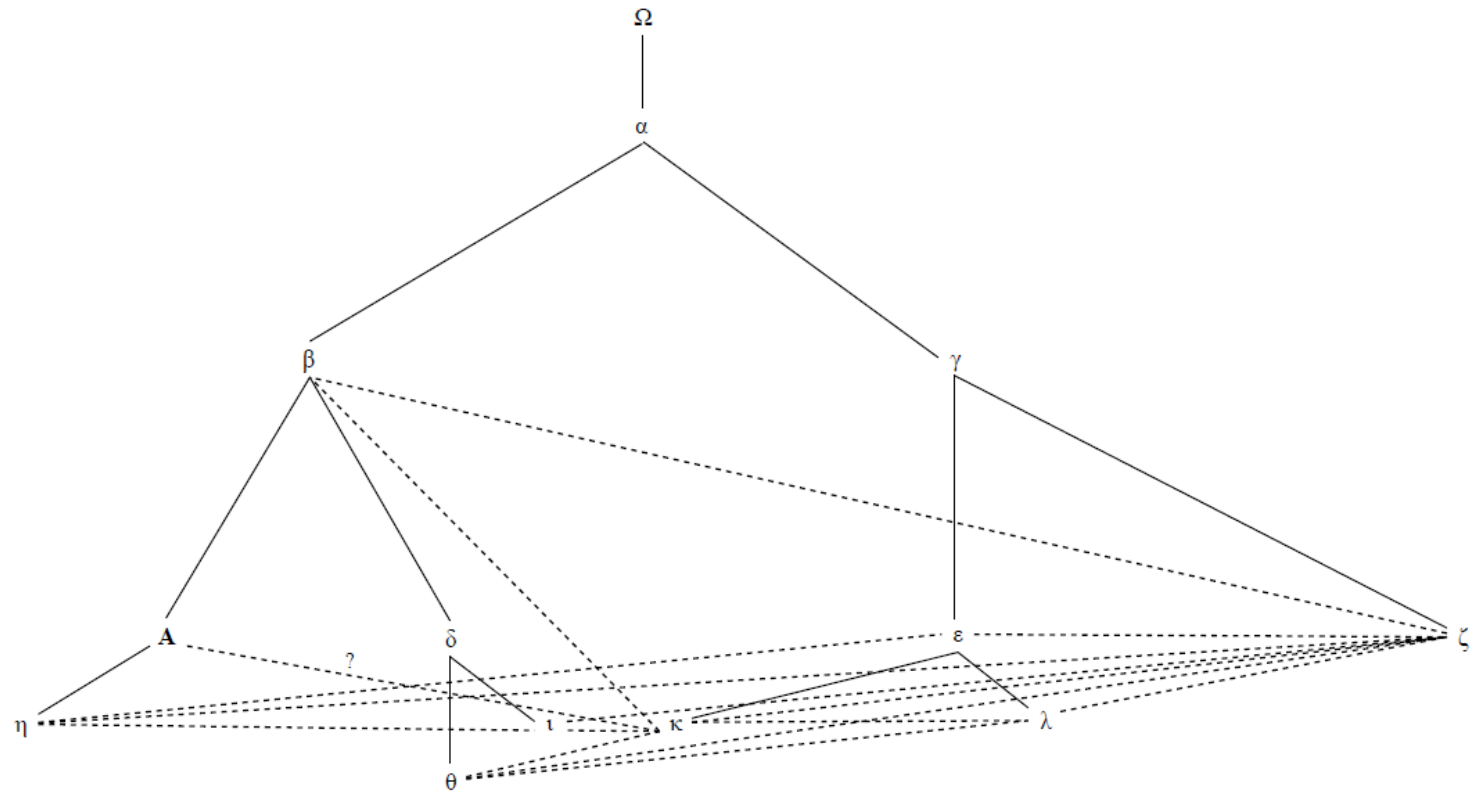


Stemma 3

IV s.

XIII s.

XV s.



APPENDIX 4. FIGURES

1. BOOK ONE. MANUSCRIPT DIAGRAMS AND MODERN RECONSTRUCTIONS

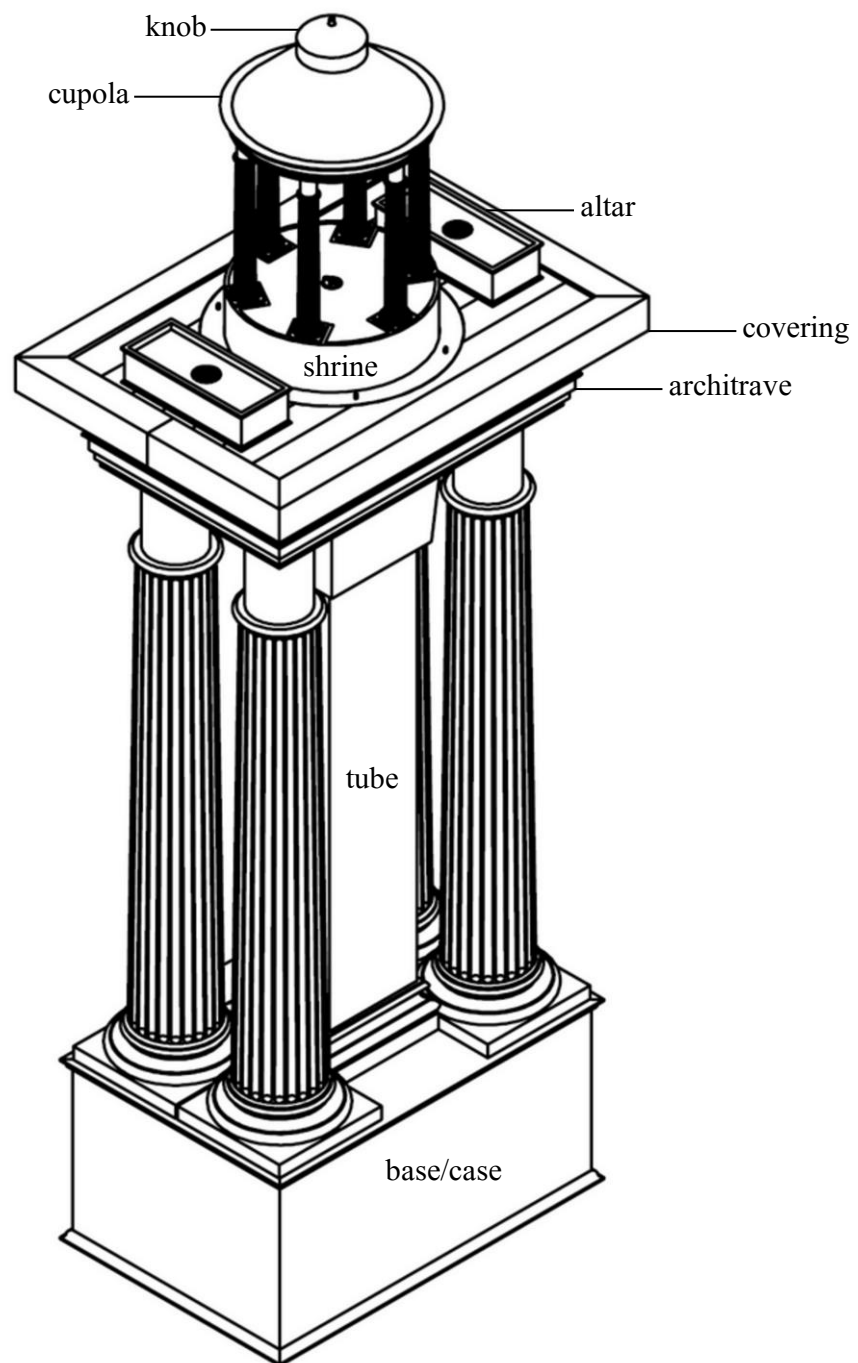


Fig. 1 Hero's mobile automaton.
Courtesy of Dr. Duncan Keenan-Jones. Image modified by the author.

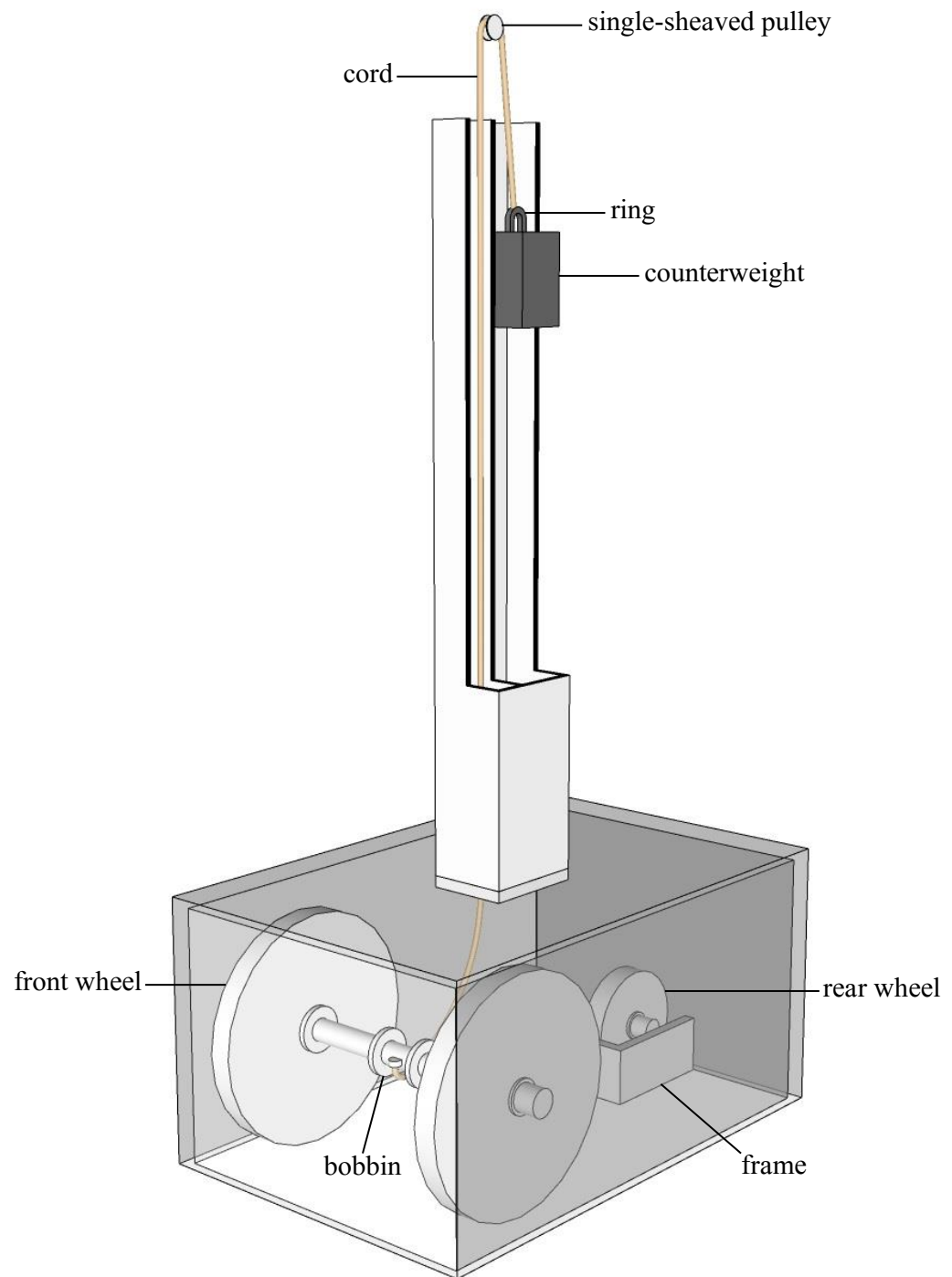


Fig. 2 Drive mechanism of Hero's mobile automaton.
 Courtesy of Arch. Riccardo Ravecca. Image modified by the author.

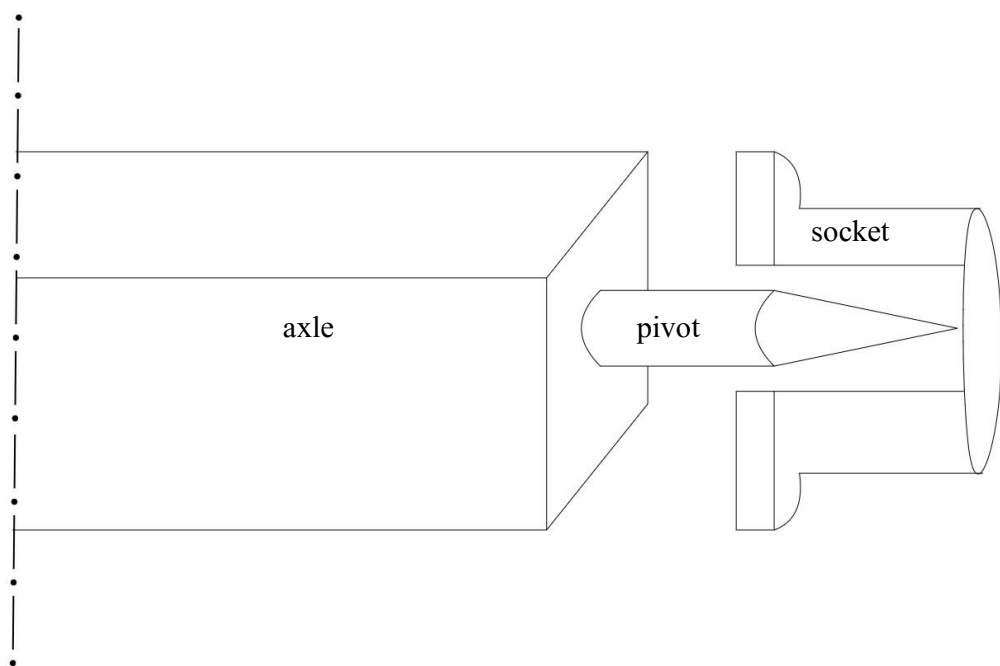


Fig. 3 Bearing arrangement of the axle of Hero's mobile automaton.

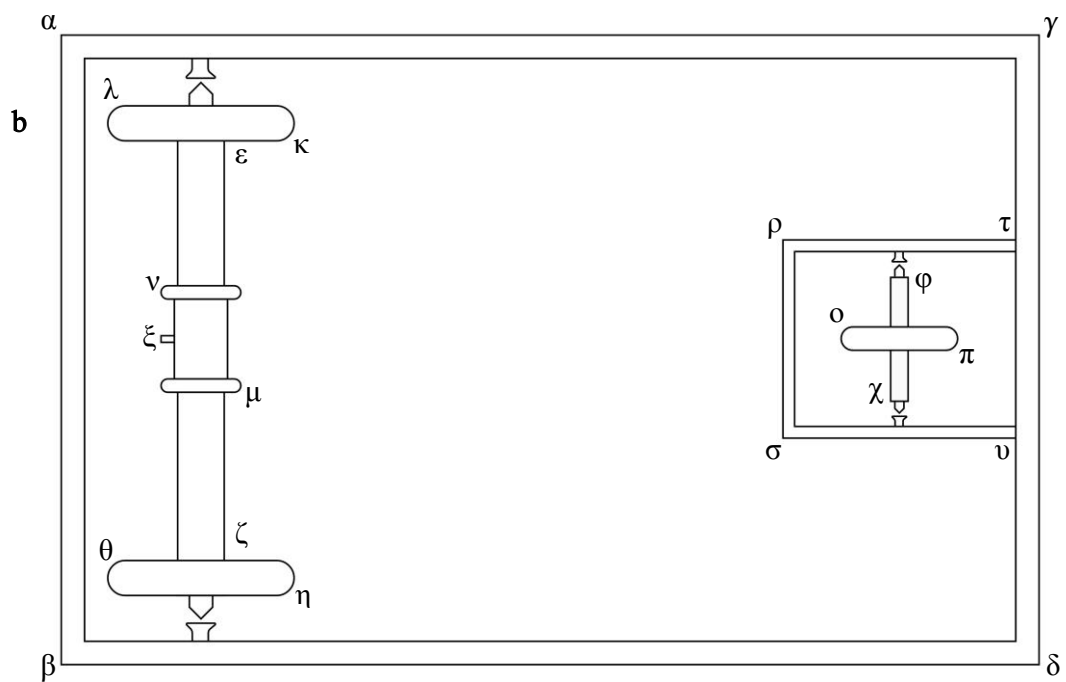
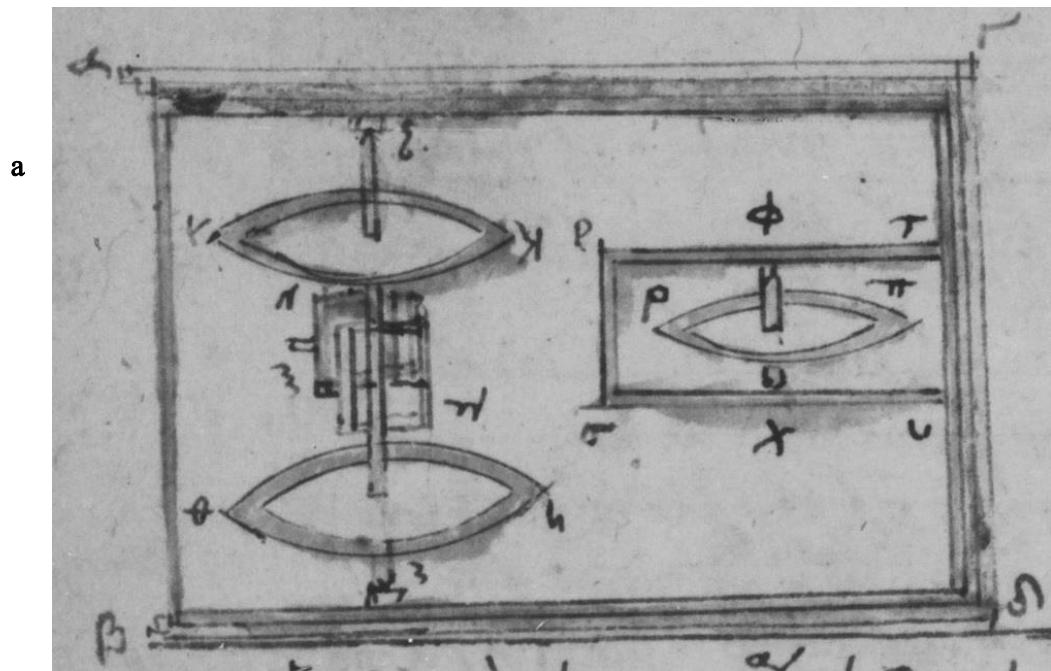


Fig. 4 Configuration for straight-line motion (plan view): **(a)** manuscript diagram (A, f. 198^v); **(b)** modern reconstruction.

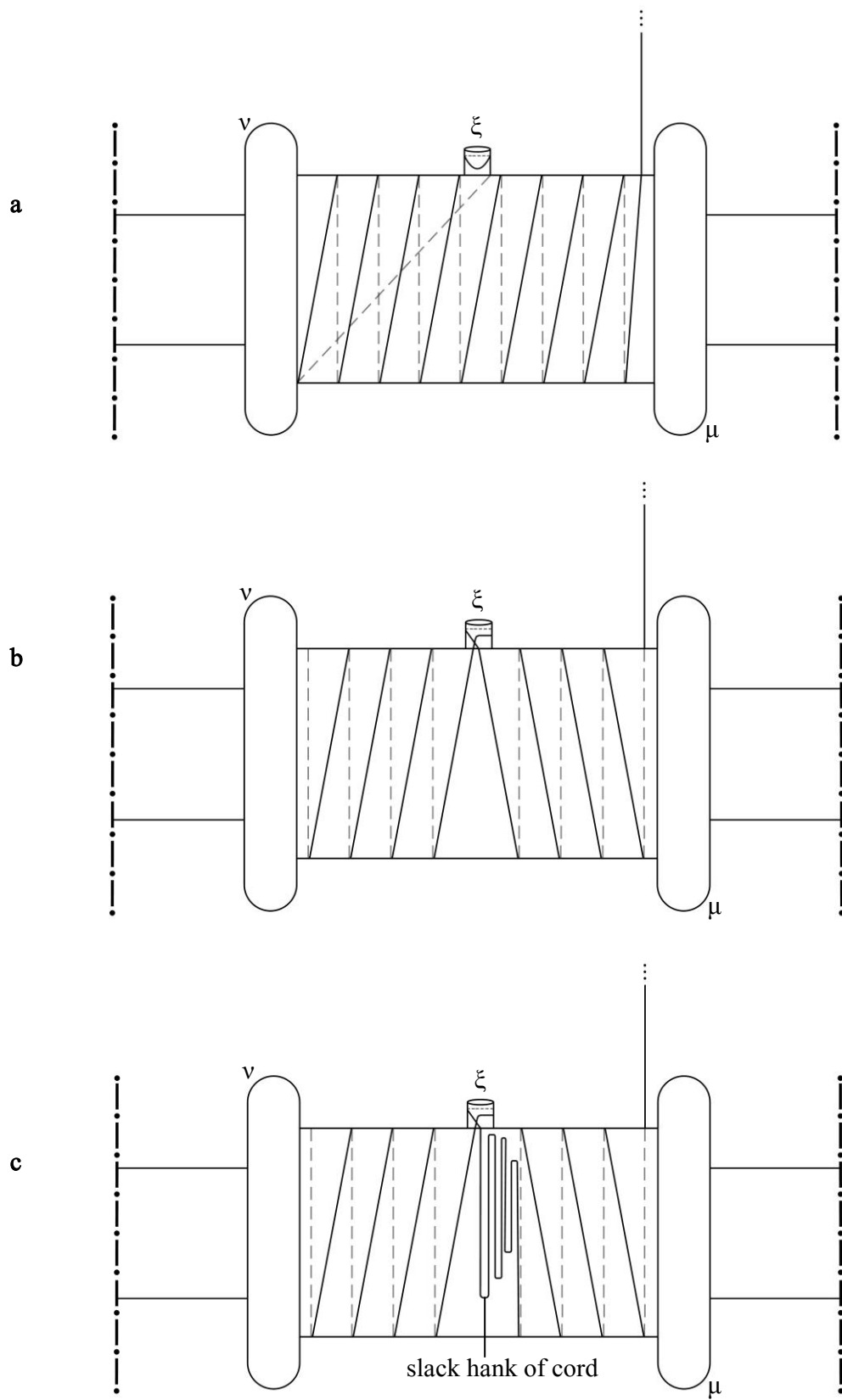
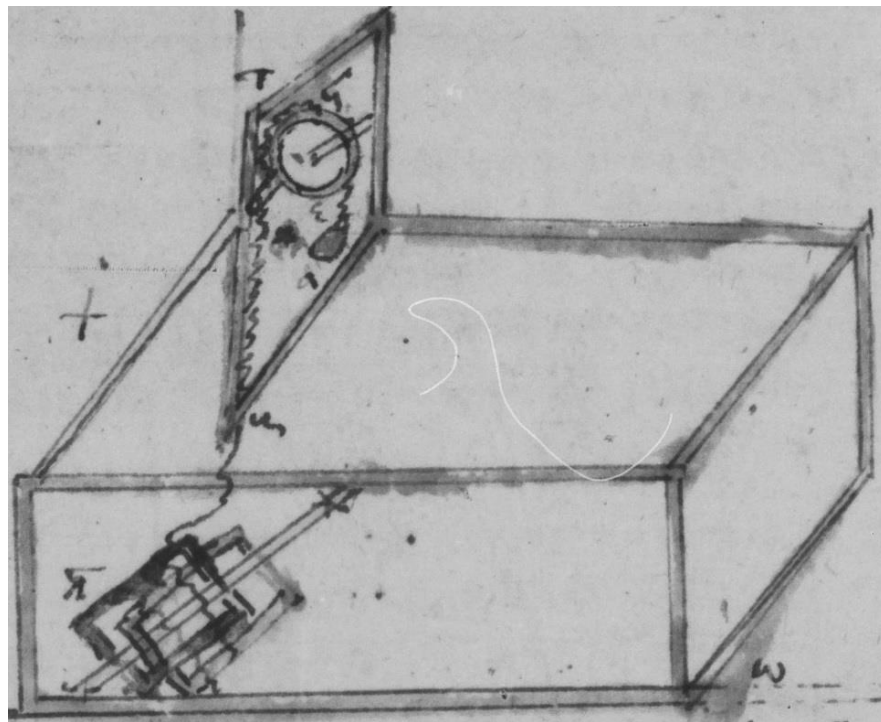


Fig. 5 Bobbin and cord arrangement for straight-line motion: **(a)** forward; **(b)** forward and backward; **(c)** forward and backward with pause.

a



b

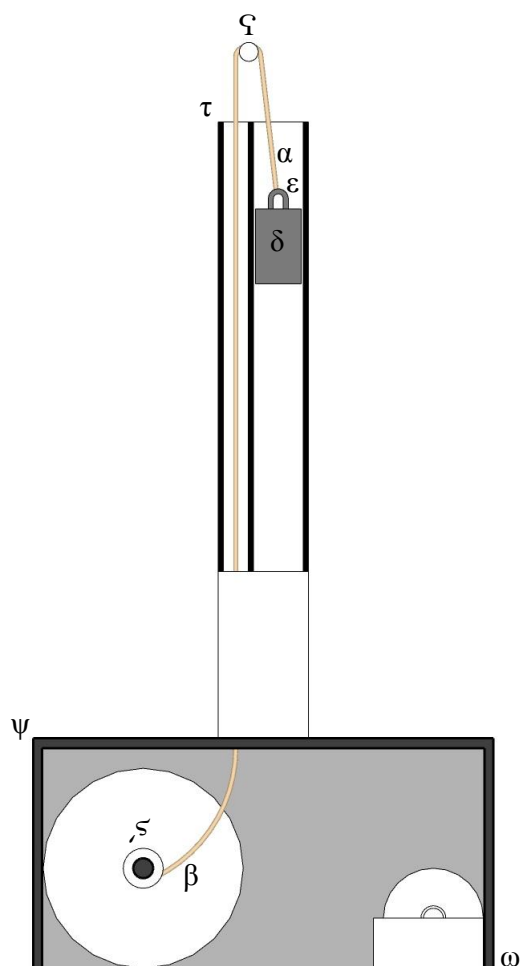
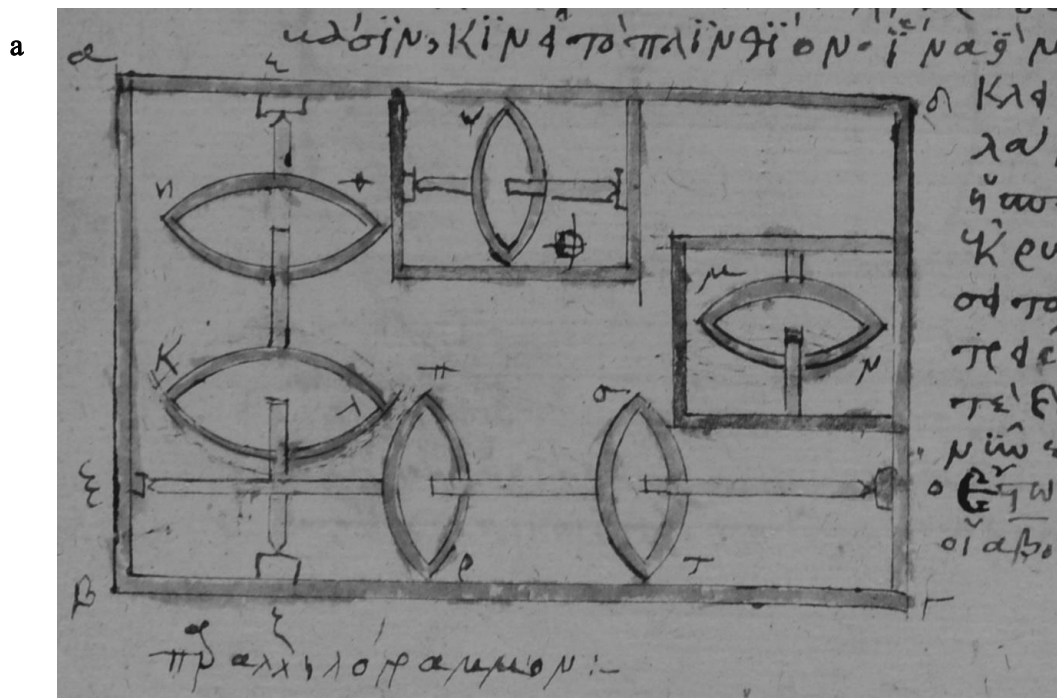


Fig. 6 Side elevation of case and tube: **(a)** manuscript diagram (A, f. 198^v); **(b)** modern reconstruction (courtesy of Arch. Riccardo Ravecca).



* Wheels $\overline{\pi\rho}$, $\overline{\sigma\tau}$ and $\overline{\upsilon\phi}$ correspond, respectively, to $\overline{\alpha\beta}$, $\overline{\gamma\delta}$ and $\overline{\epsilon\zeta}$ as first introduced in X.1. Axle $\overline{\xi\theta}$ corresponds to $\overline{\eta\theta}$, whereas the axle of wheel $\overline{\upsilon\phi}/\overline{\epsilon\zeta}$ is later labelled $\overline{\xi\theta}$ (cf. Fig. 10).

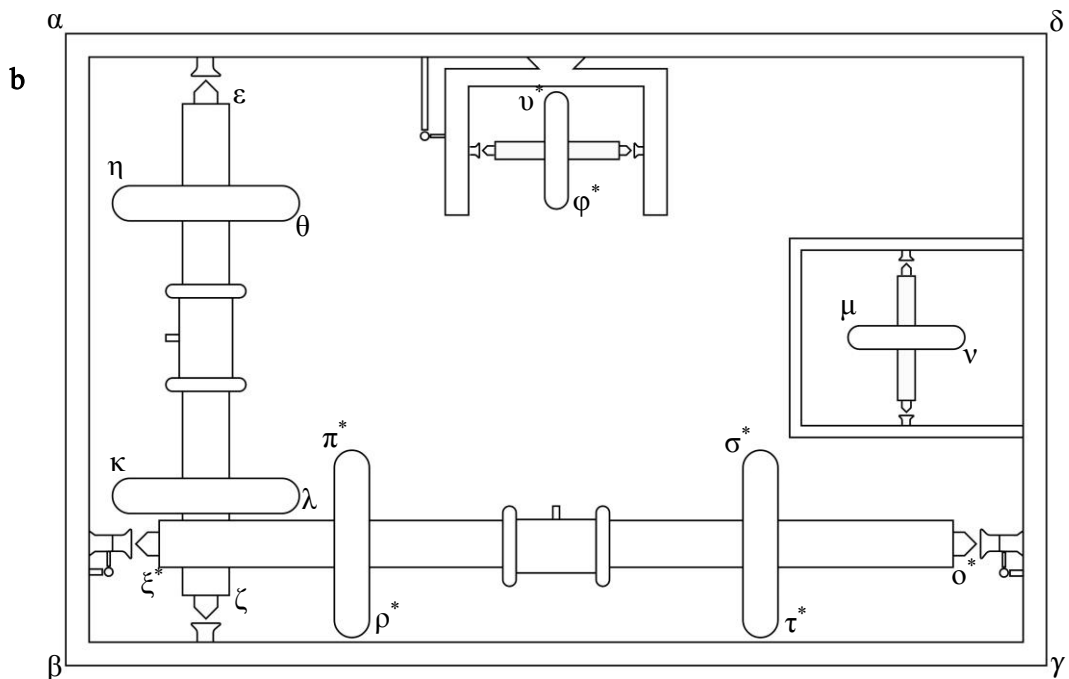


Fig. 8 Configuration for rectangular motion (plan view): (a) manuscript diagram (A, f. 199^v); (b) modern reconstruction.

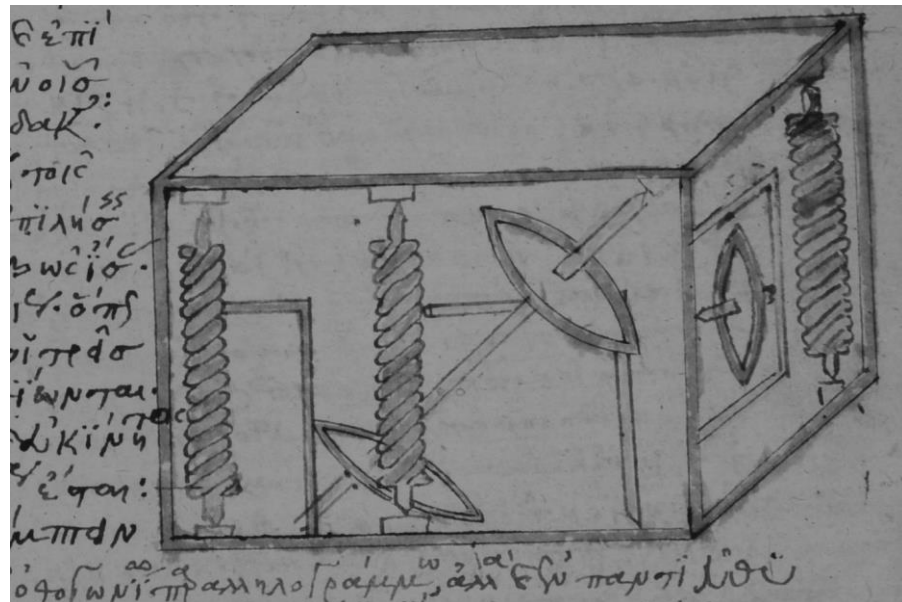


Fig. 9 Configuration for rectangular motion (side view).
A, f. 200^r.

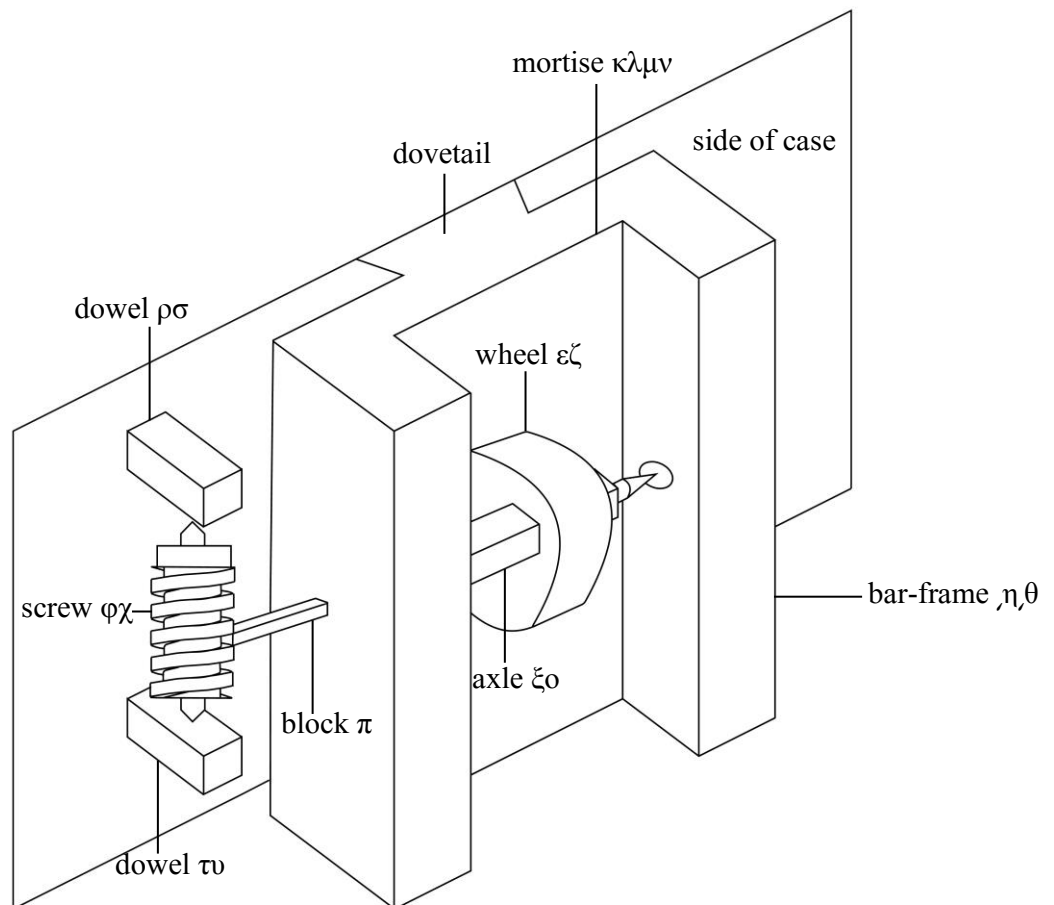


Fig. 10 Mechanism for raising and lowering wheel $\overline{\varepsilon\zeta/\overline{v\phi}}$.

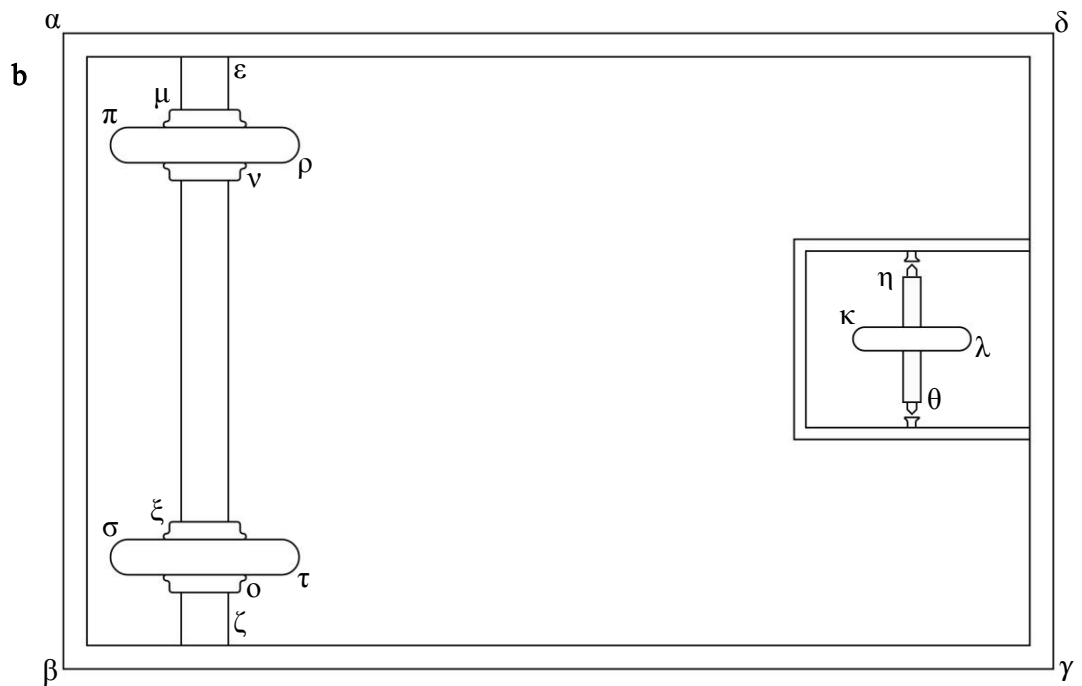
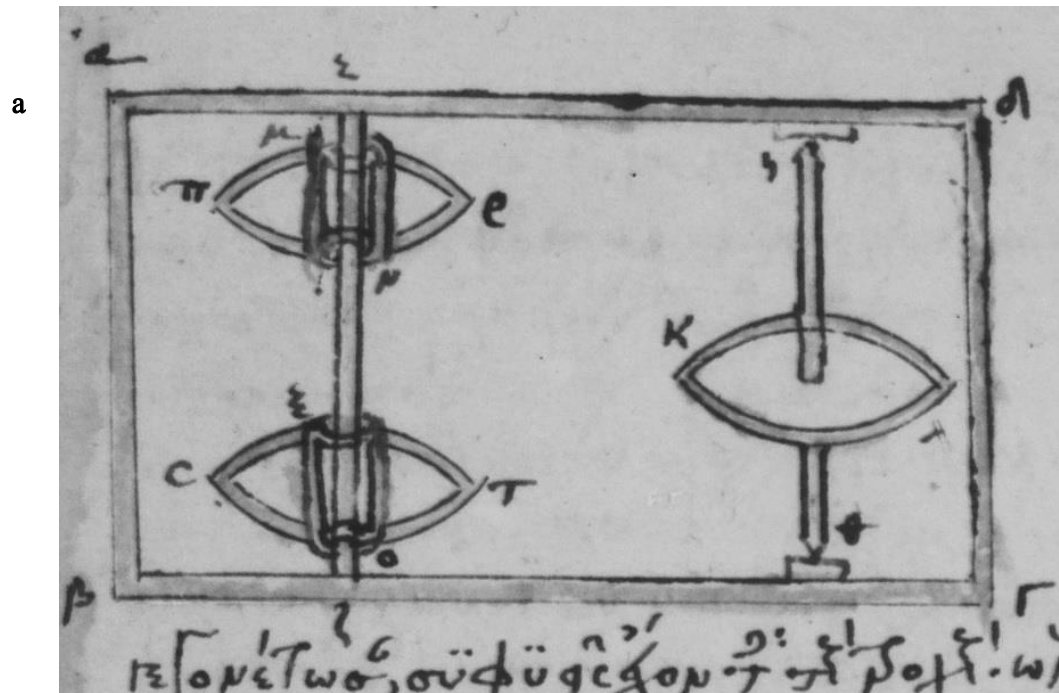


Fig. 11 First configuration for snake-like motion (plan view): **(a)** manuscript diagram (A, 201^v); **(b)** modern reconstruction, with rear wheel encased in a frame as in putative archetype.

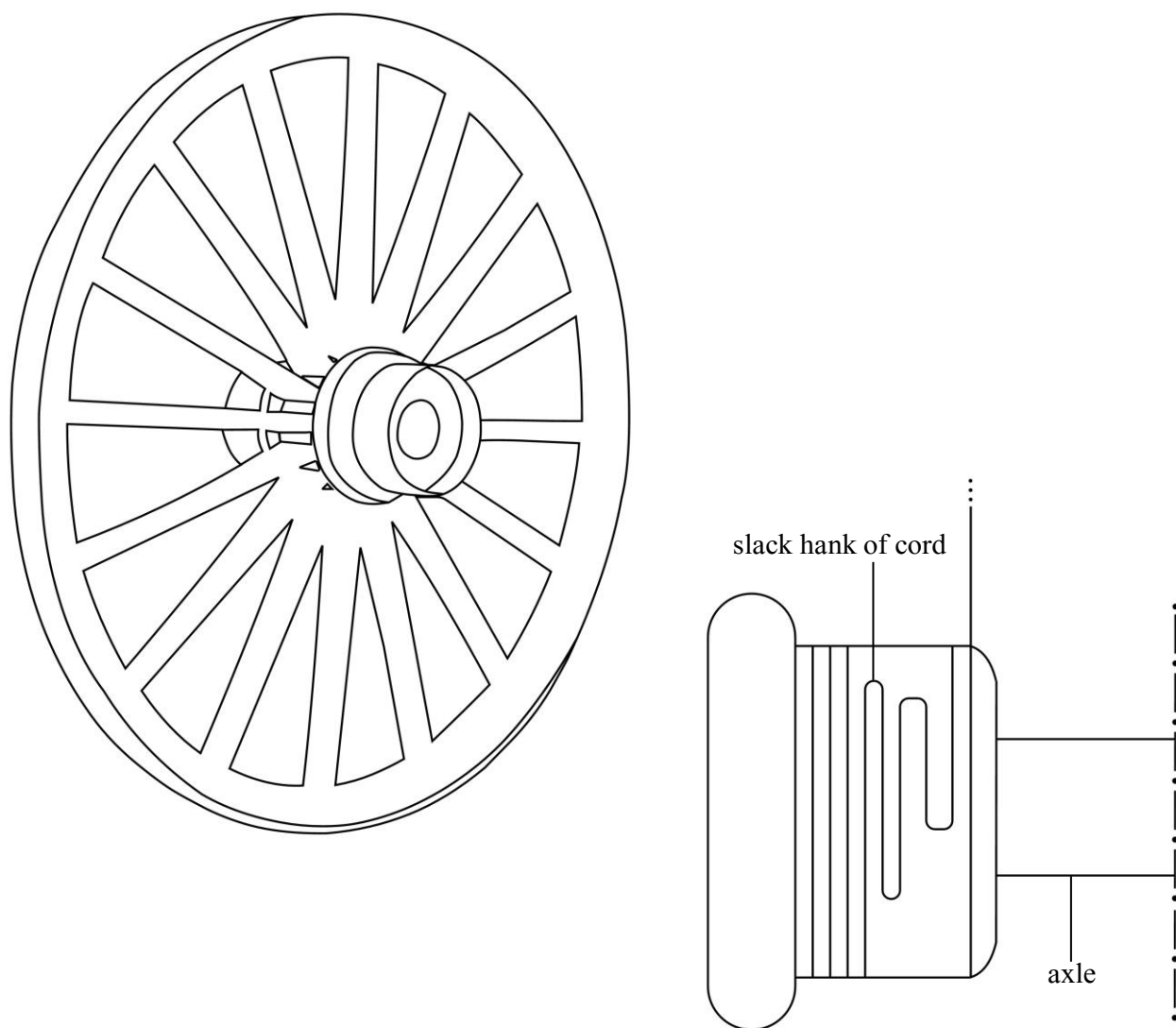


Fig. 12 Wheel $\overline{\pi\rho}$ mounted on hub (left) and close-up of hub with cord wound around it (right).

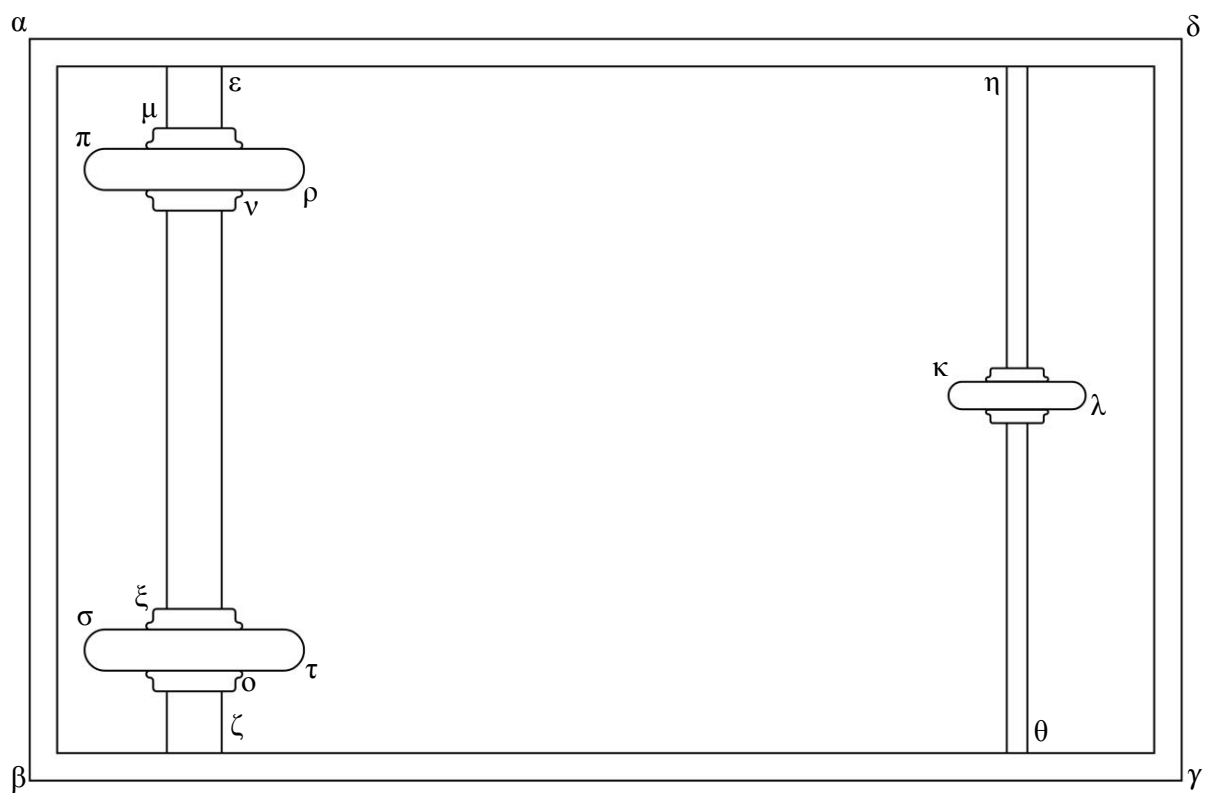


Fig. 13 Second configuration for snake-like motion (plan view).

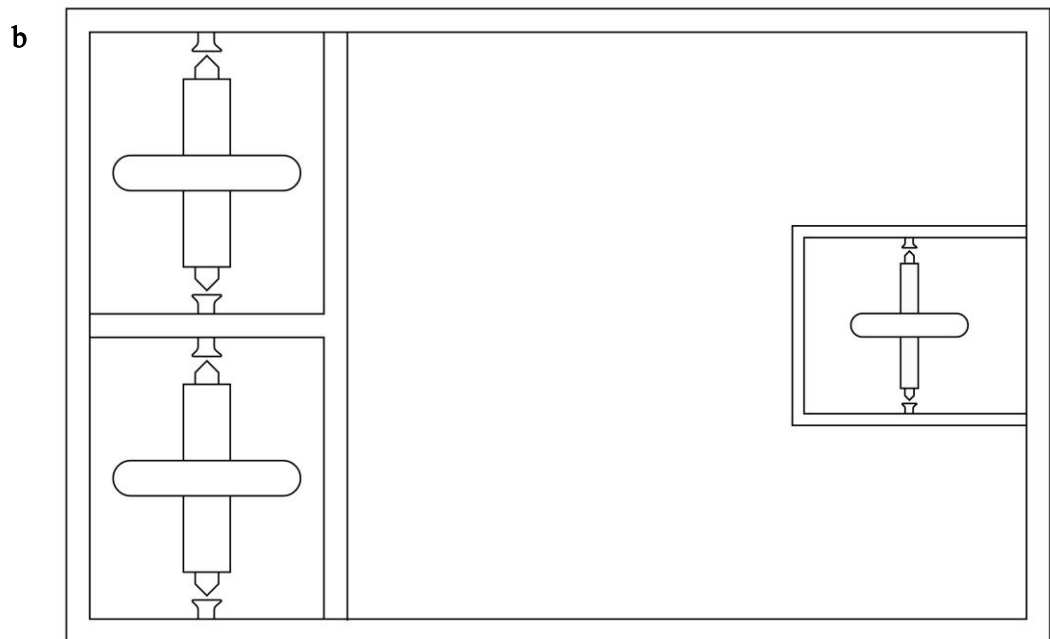
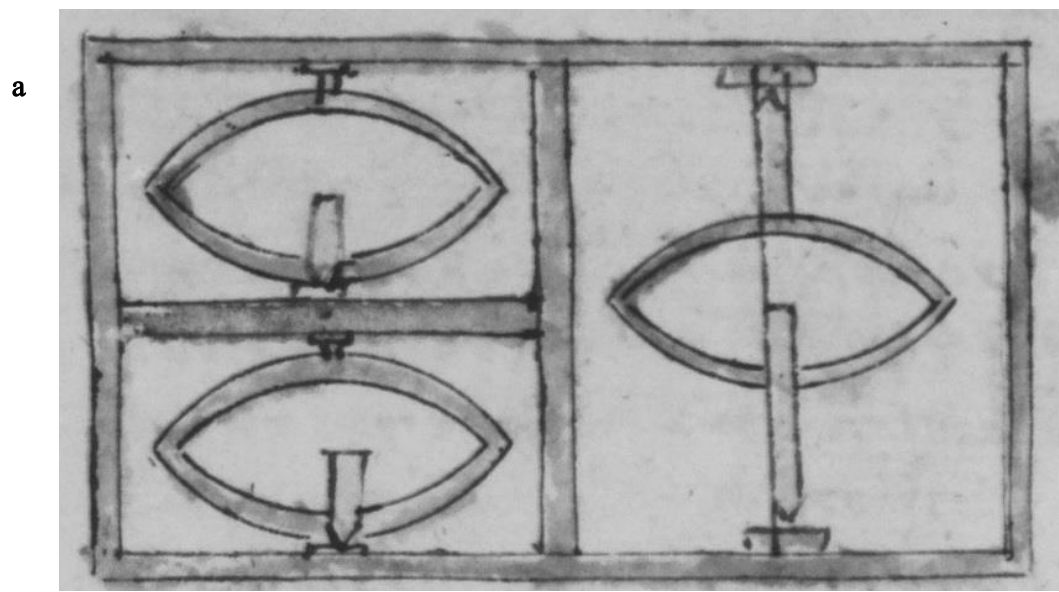


Fig. 14 Third configuration for snake-like motion (plan view): **(a)** manuscript diagram (**A**, f. 201'), **(b)** modern reconstruction, with rear wheel encased in a frame as in putative archetype.

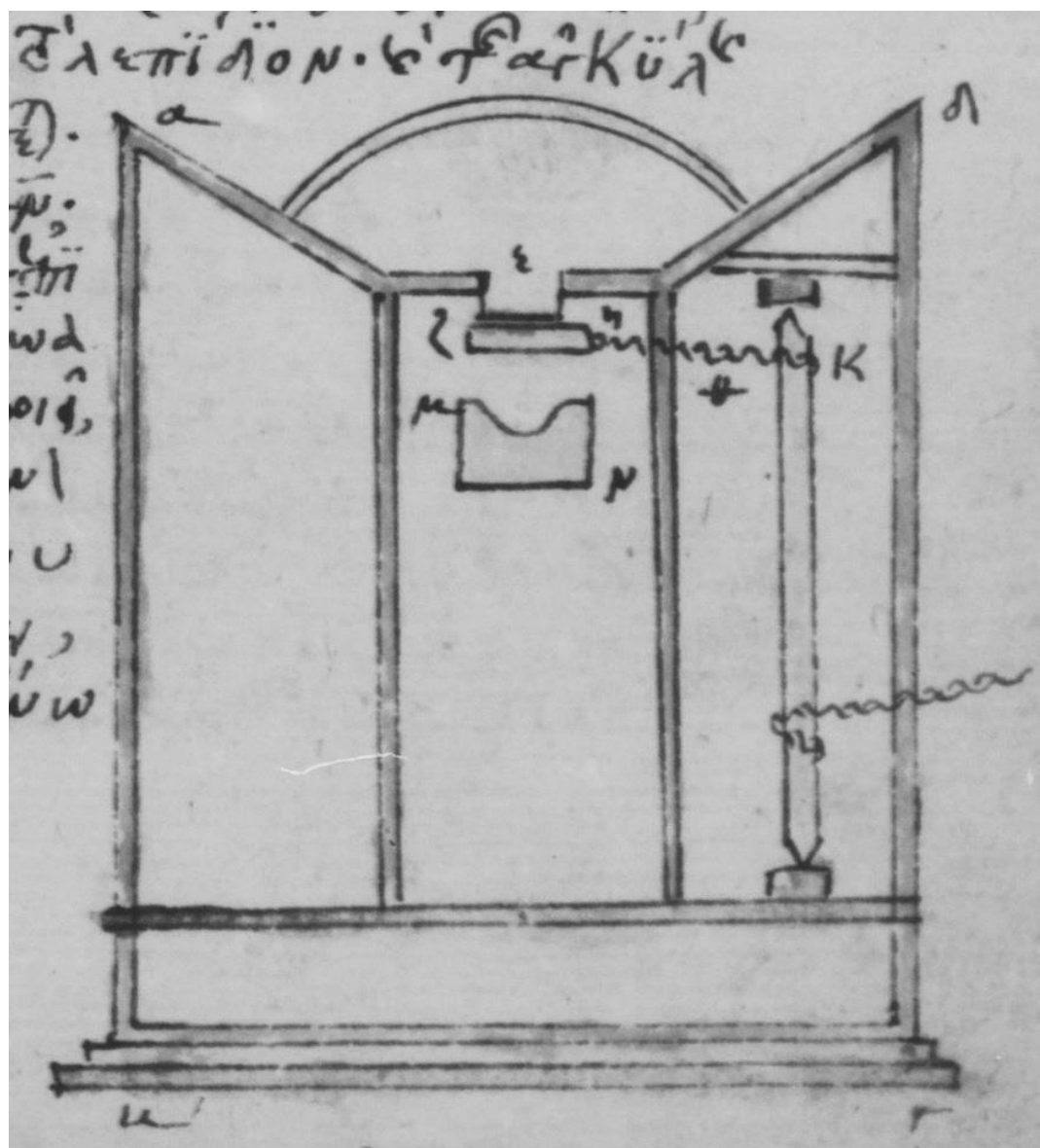


Fig. 15 Kindling altar of Dionysus (front view).
A, f. 201^r.

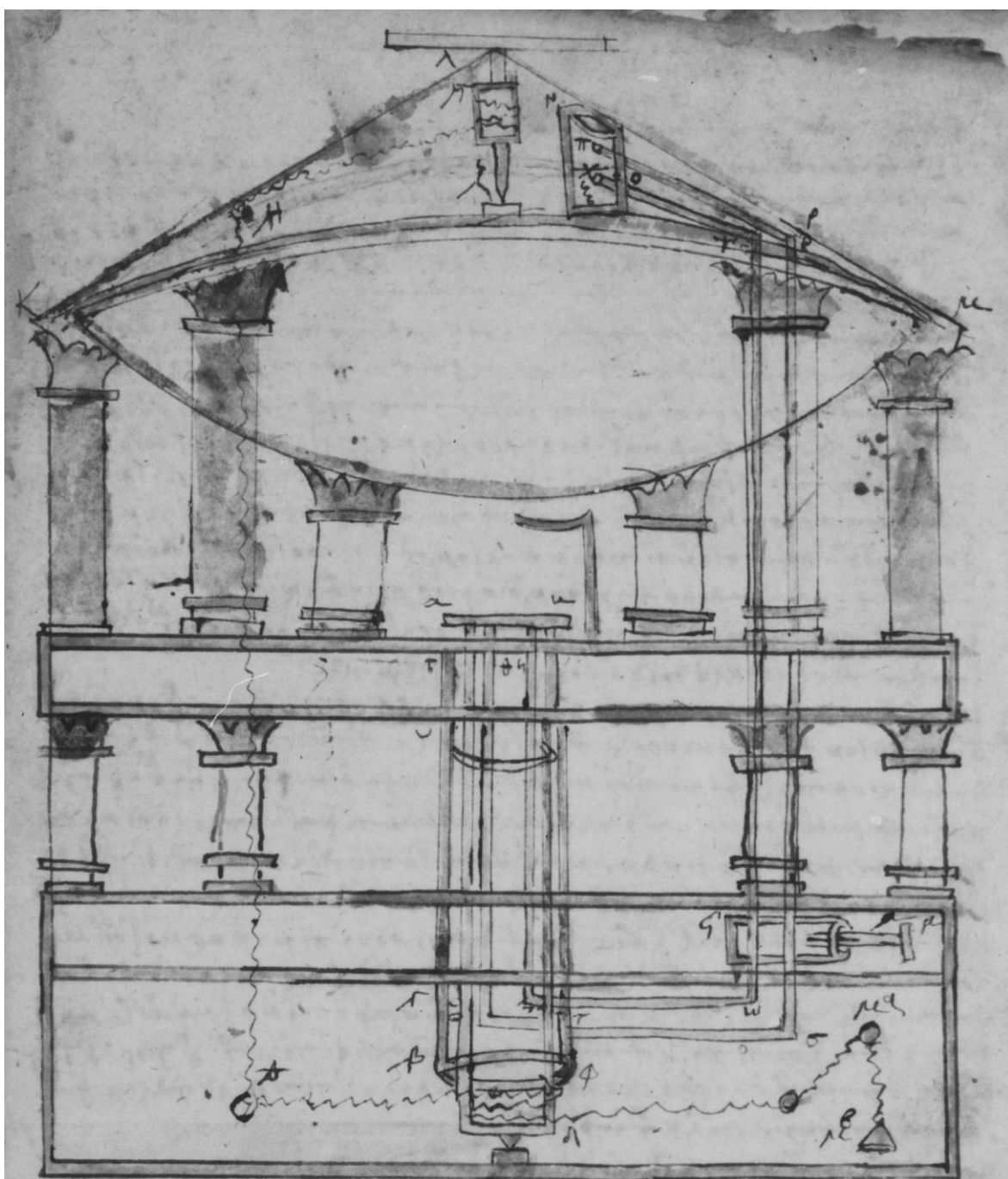


Fig. 16 Piping system for libation of milk and wine (front view).
A, f. 202^r.

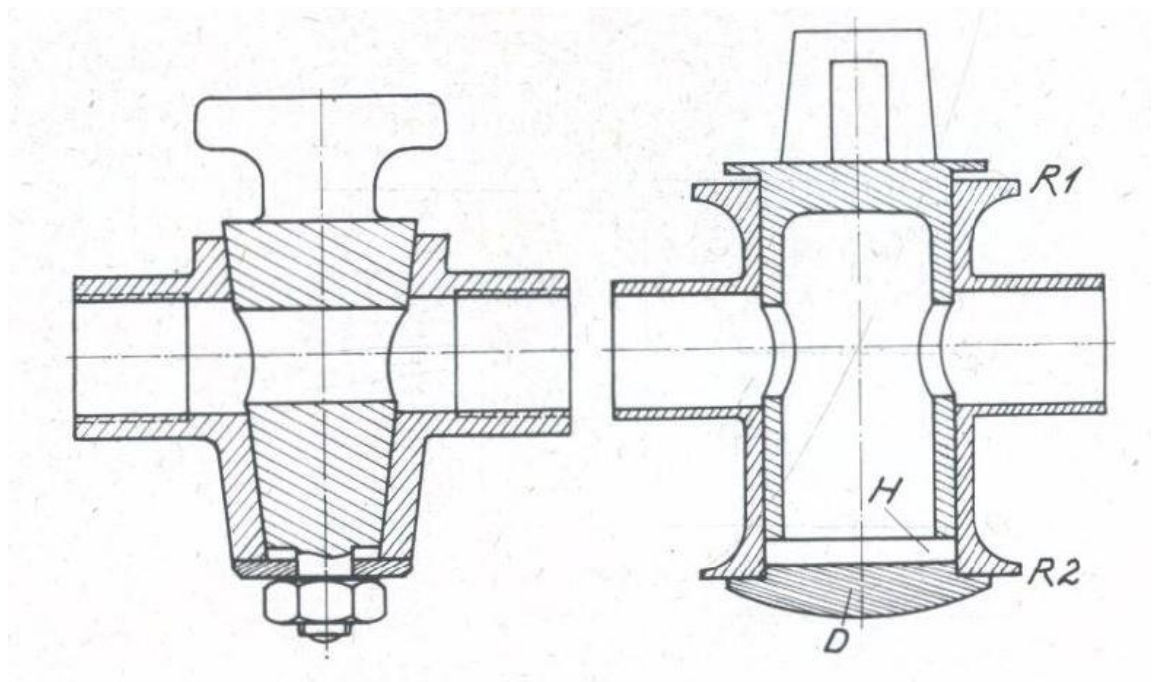


Fig. 17 Modern gas tap (left) vs ancient water tap (right).
Reprinted from Kretzschmer (1960: 91 Fig. 25).

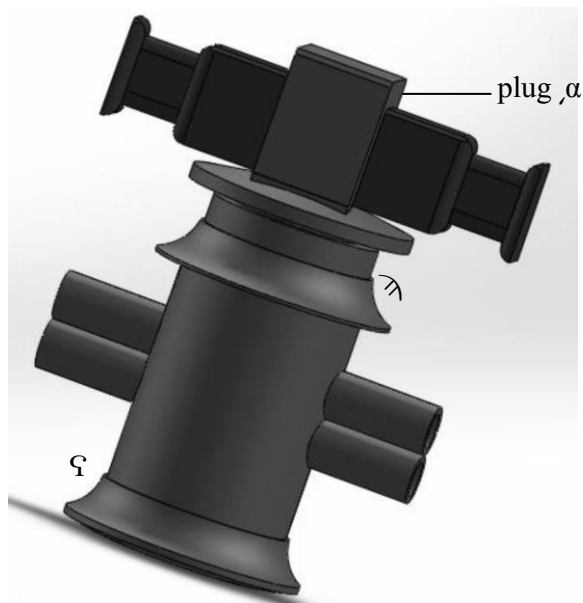


Fig. 18 Hero's double-piped tap.
Courtesy of Dr. Duncan Keenan-Jones. Image modified by the author.

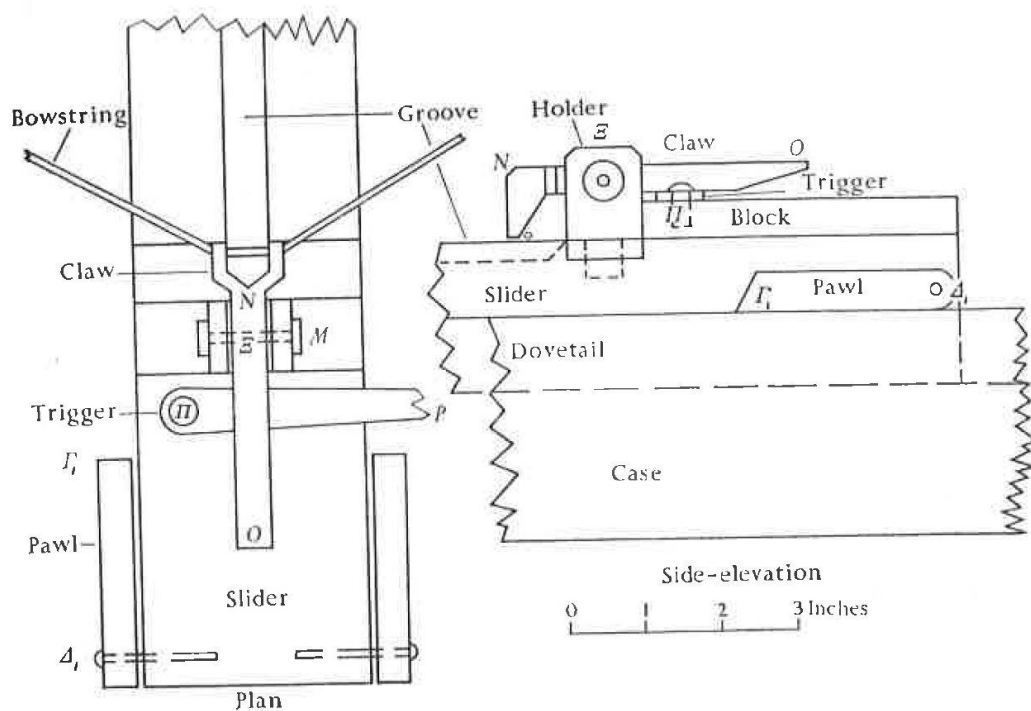


Fig. 19 Trigger mechanism for Hero's belly-bow (γαστραφέτης).
Reprinted from Marsden (1971: 48 Fig. 4).

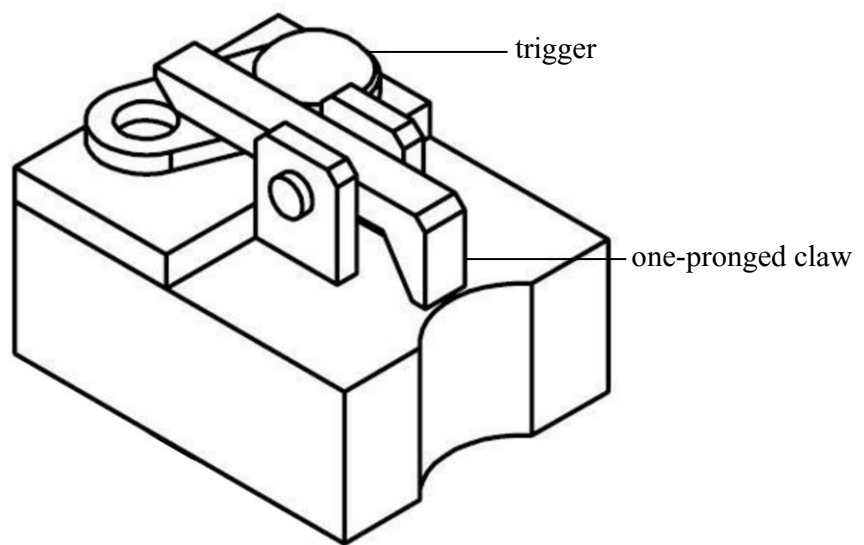


Fig. 20 Trigger mechanism for weight μ^{β} .
Courtesy of Dr. Duncan Keenan-Jones. Image modified by the author.

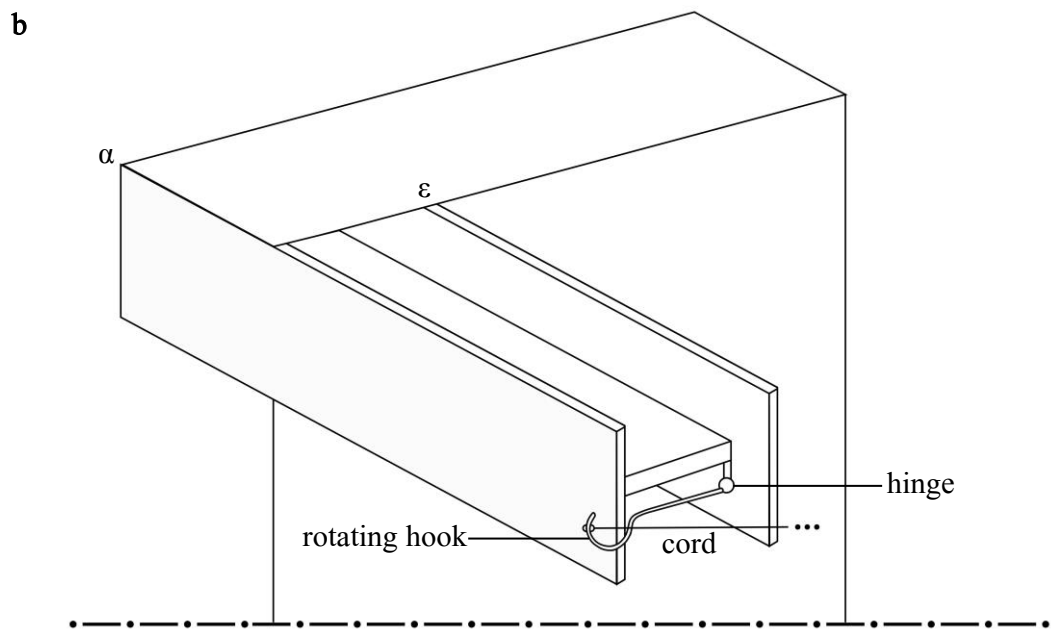
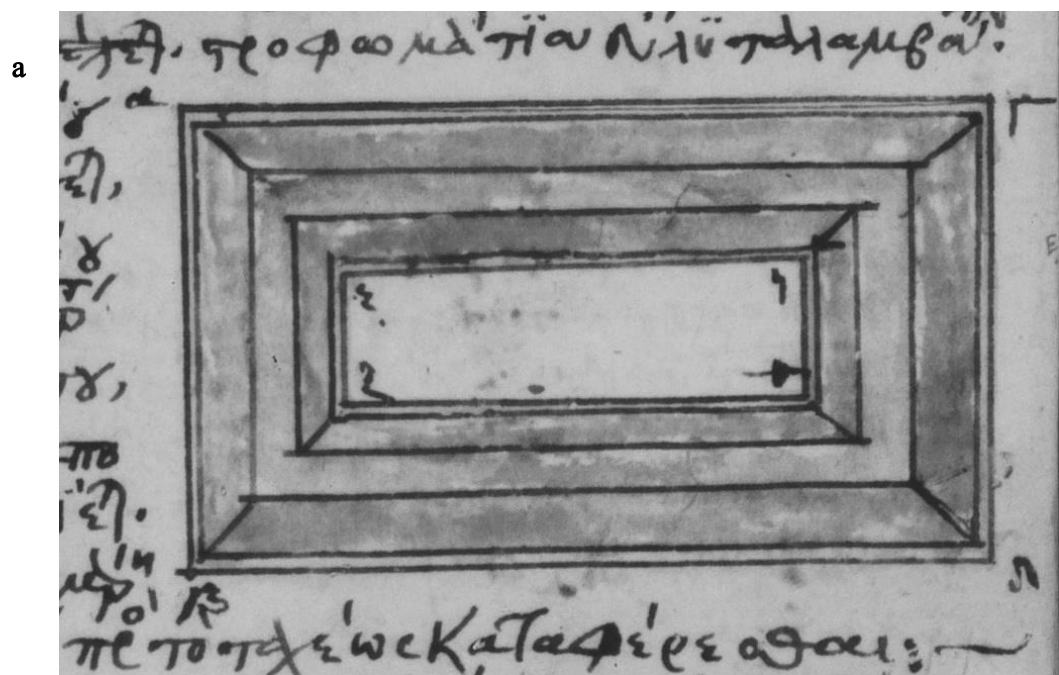
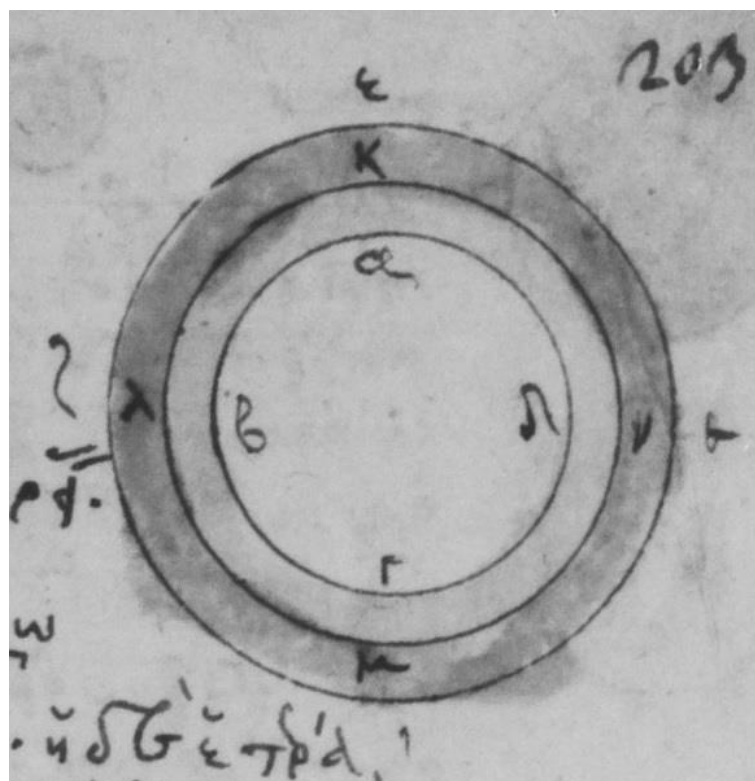


Fig. 21 Parapet(s) for descending garlands: **(a)** manuscript diagram (plan view; A, f. 202^v); **(b)** modern reconstruction (side view).

a



b

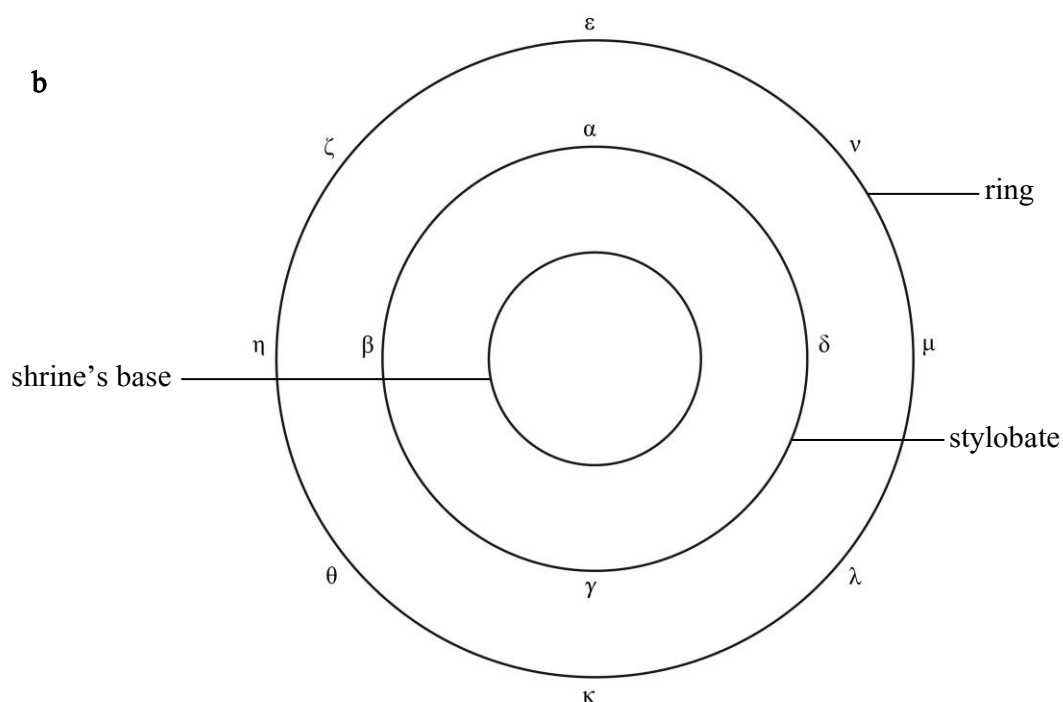


Fig. 22 Stylobate, ring (ἵρυς) and base of the shrine (plan view):
(a) manuscript diagram (A, f. 203^r); **(b)** modern reconstruction, with letters corrected as in putative archetype (clipart courtesy FCIT; image modified by the author).

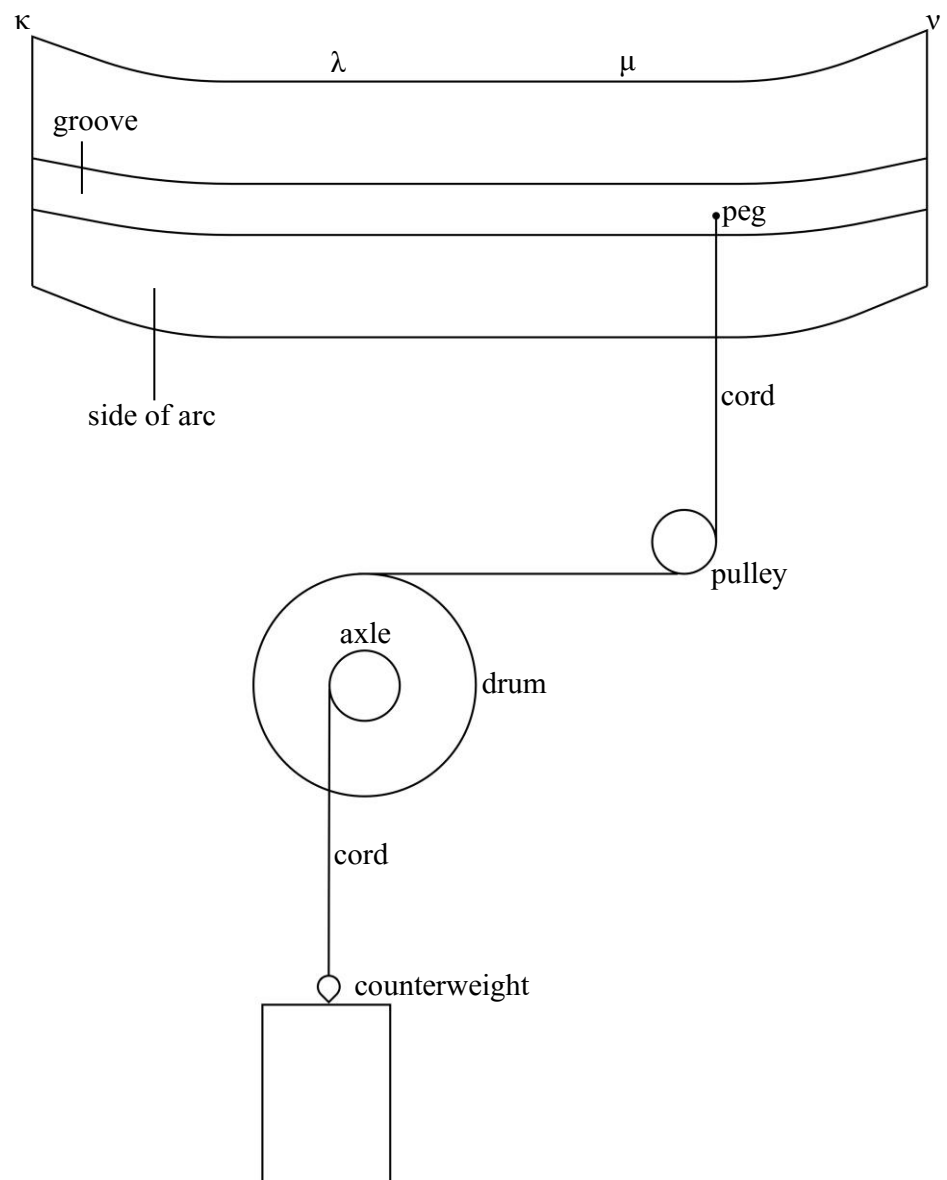
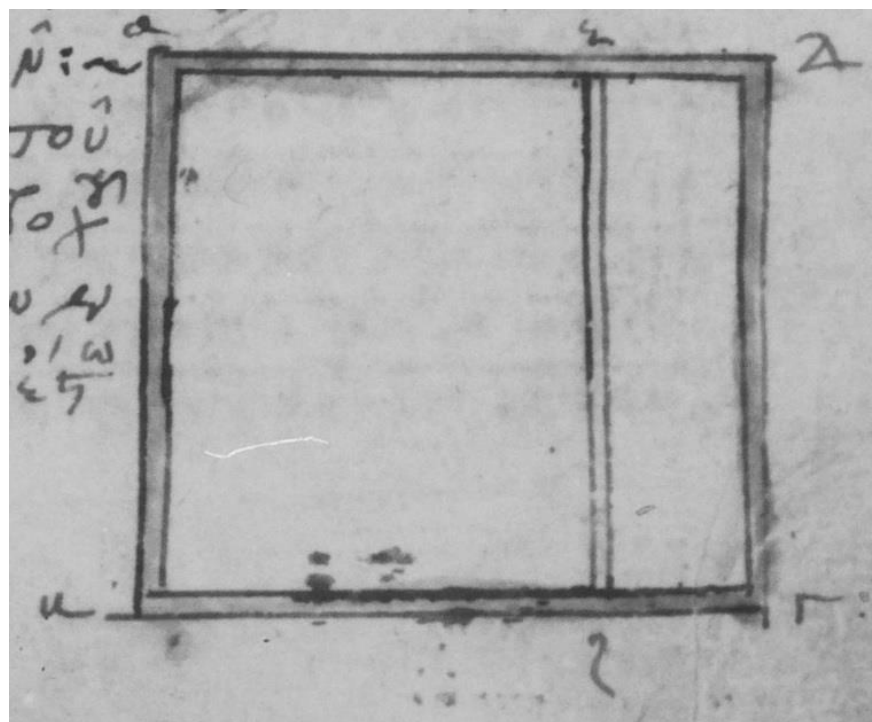


Fig. 23 Transmission system for dancing Bacchantes.

a



b

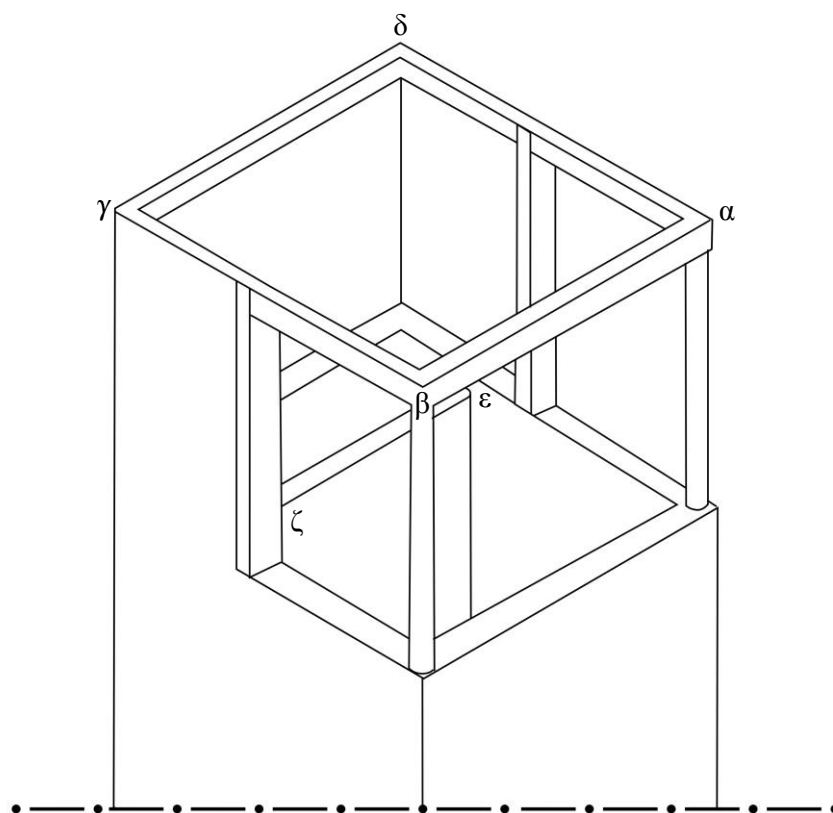
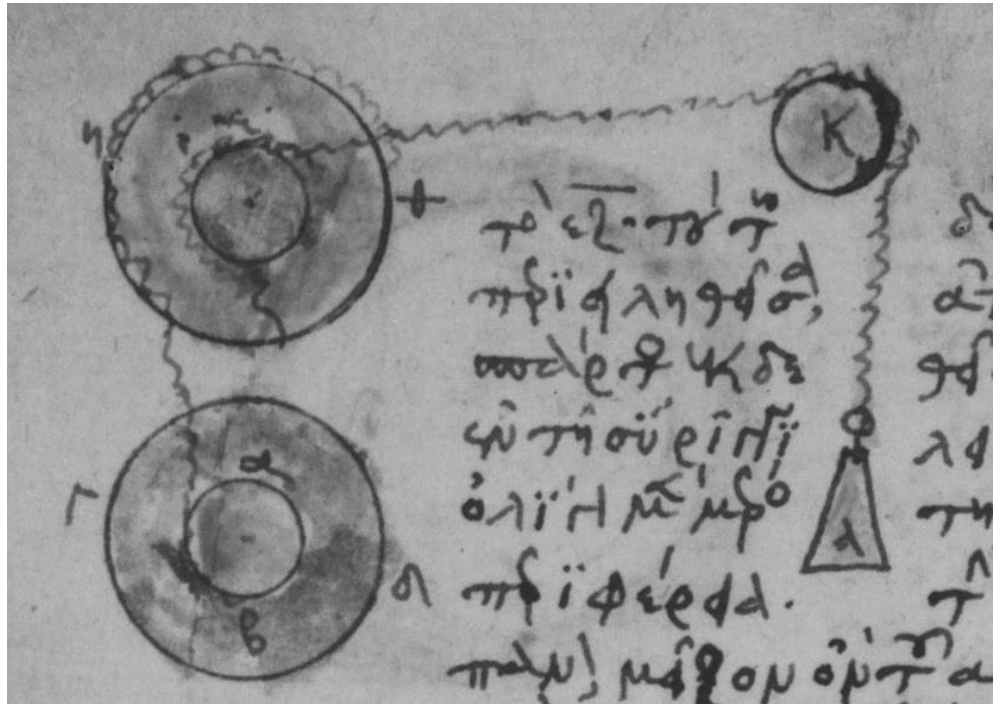


Fig. 24 Single σύριγξ: (a) manuscript diagram (plan view; A, f. 203^v); (b) modern reconstruction.

a



b

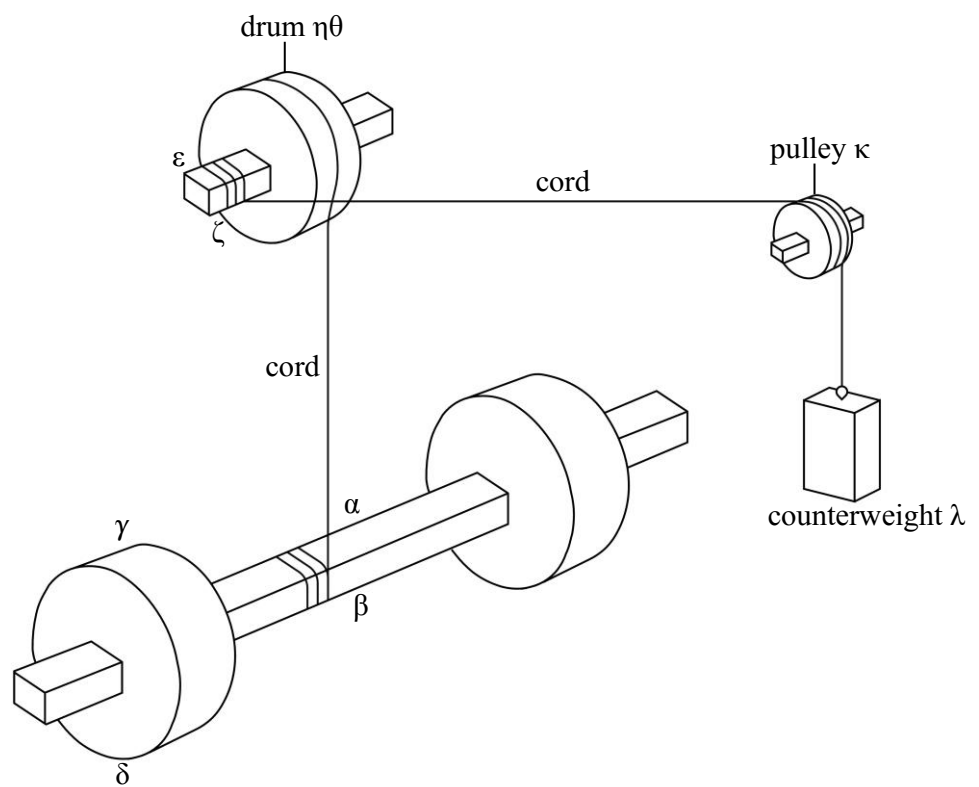
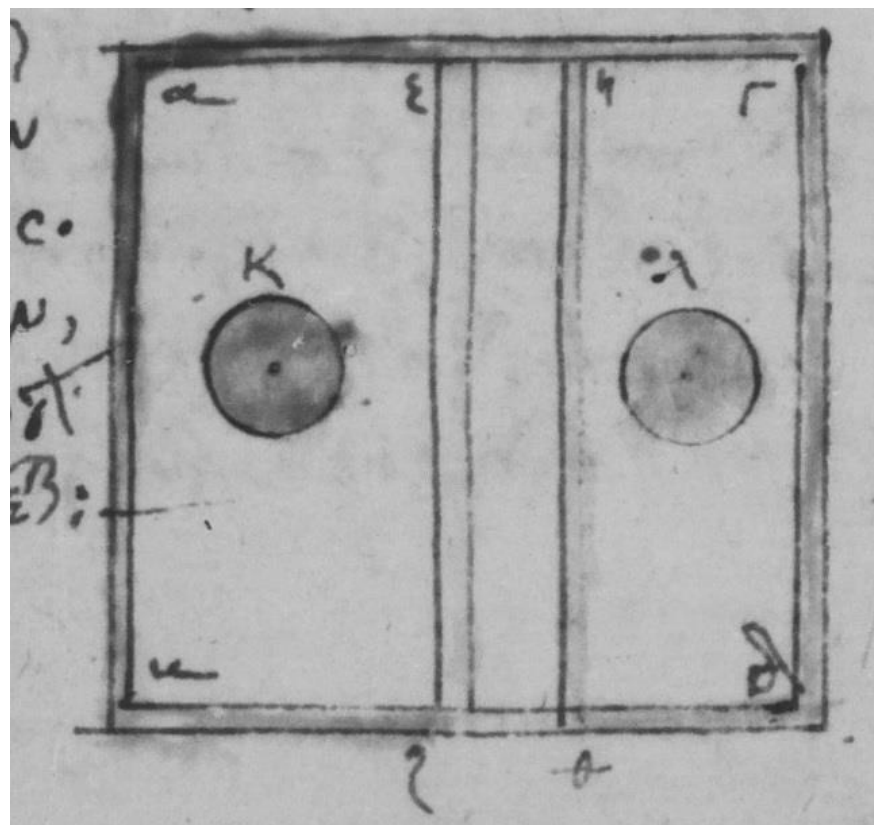


Fig. 25 Transmission system for extending the range of the mobile automaton: **(a)** manuscript diagram (side view; A, f. 230^v); **(b)** modern reconstruction.

a



b

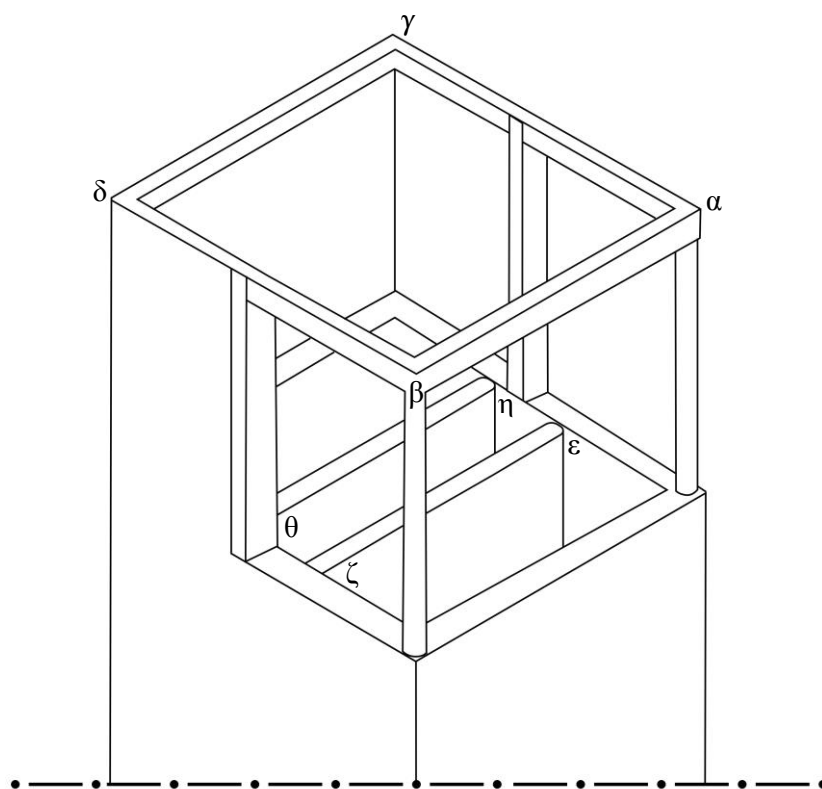


Fig. 26 Double σύριγξ: **(a)** manuscript diagram (plan view; A, f. 203^v); **(b)** modern reconstruction.

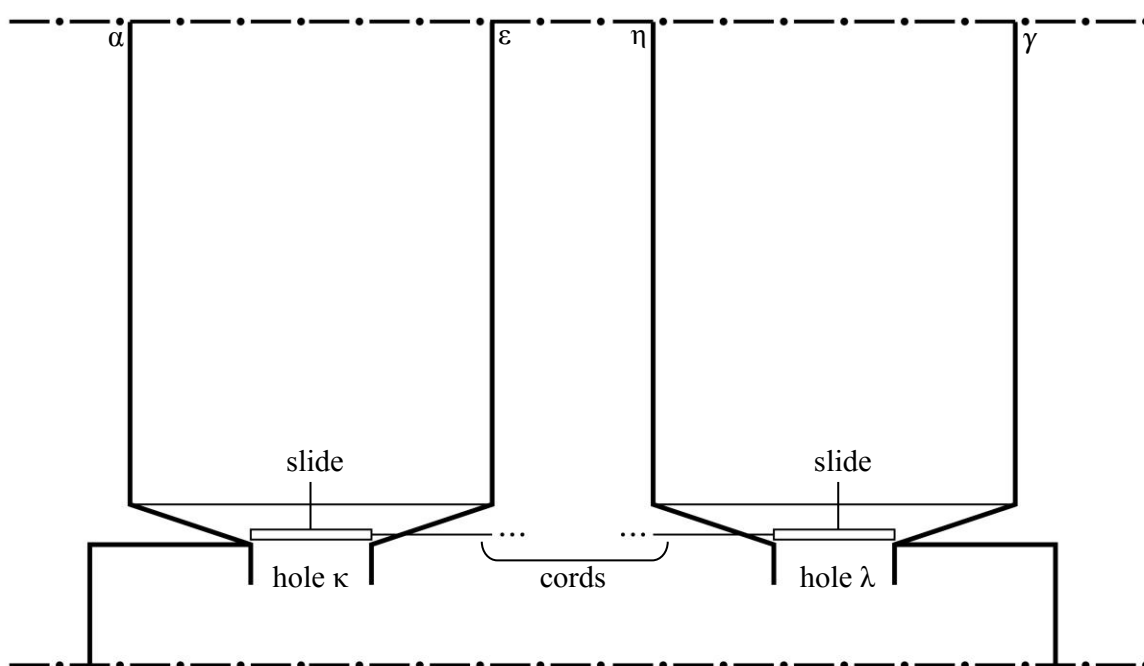


Fig. 27 Bottom of double σύργιξ with slides (front view).

2. BOOK TWO. MANUSCRIPT DIAGRAMS

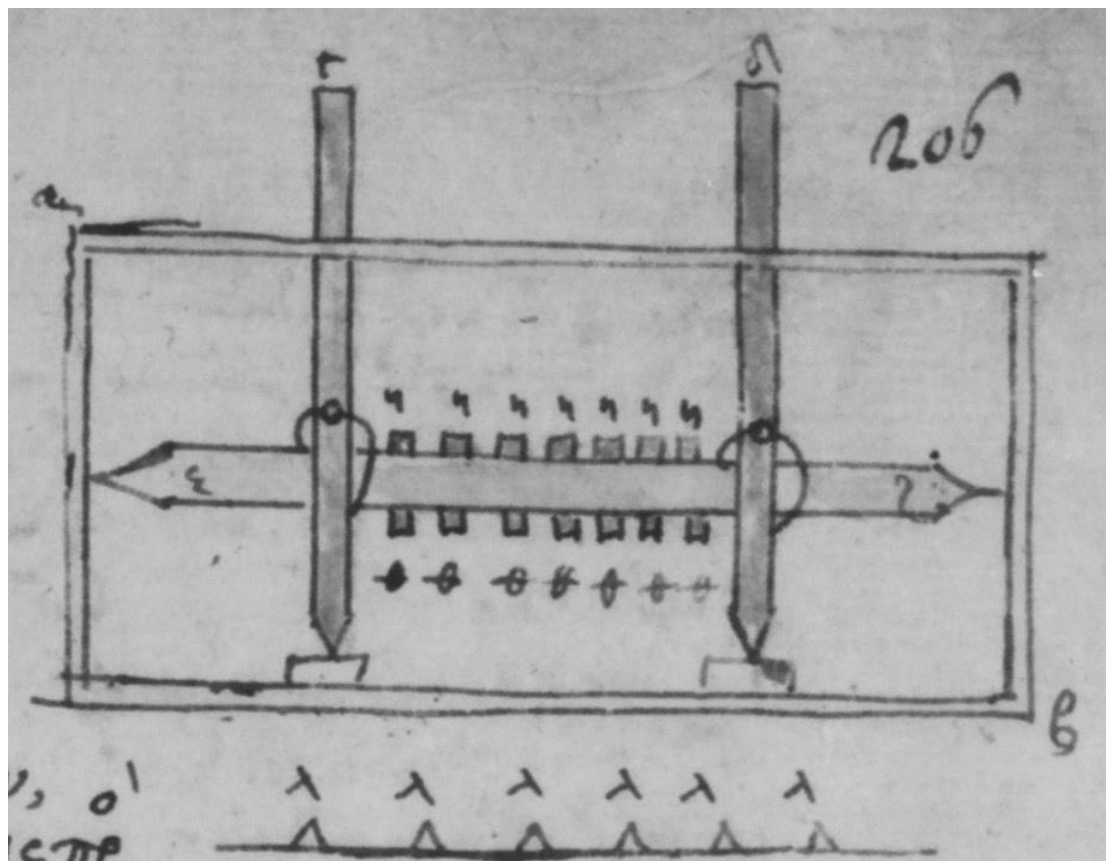


Fig. 28 Door mechanism for Hero's stationary automaton (front view).
A, f. 206^r.

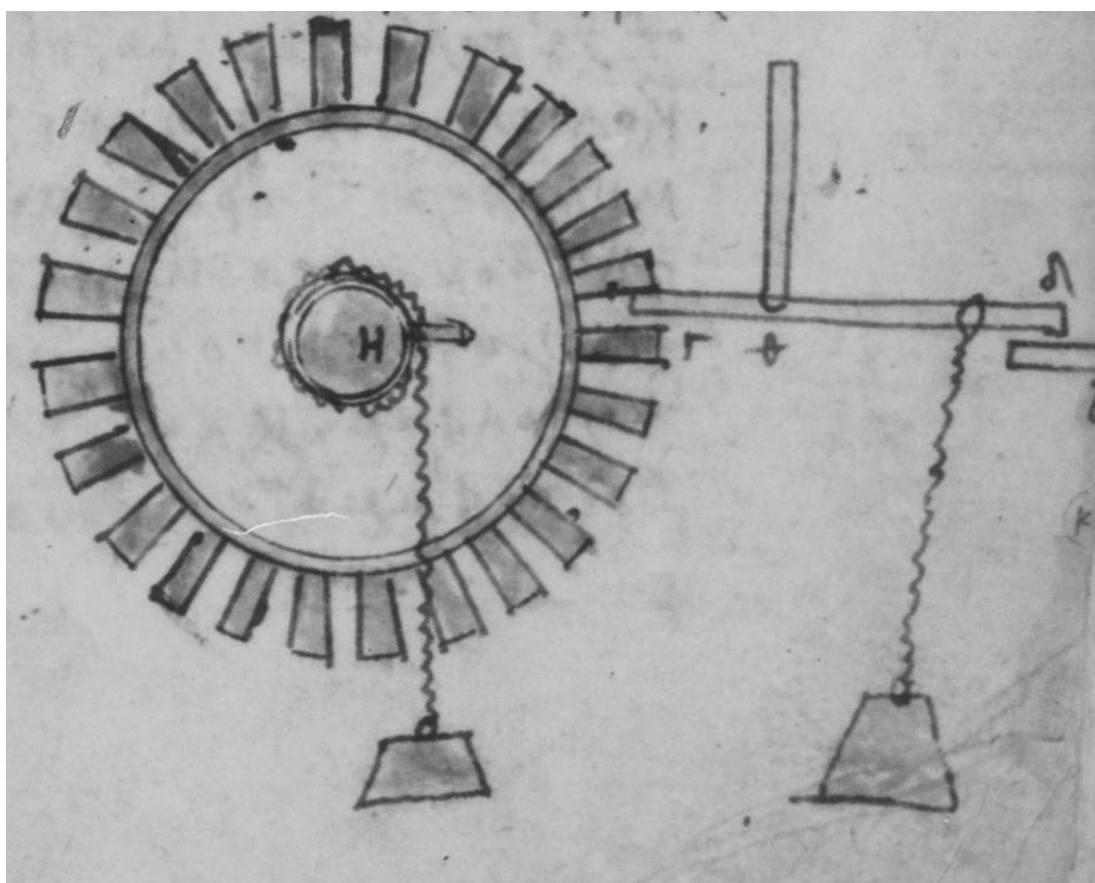


Fig. 29 Starwheel and ὑσπλήγγιον assembly for moving arms (side view).
A, f. 205^r.

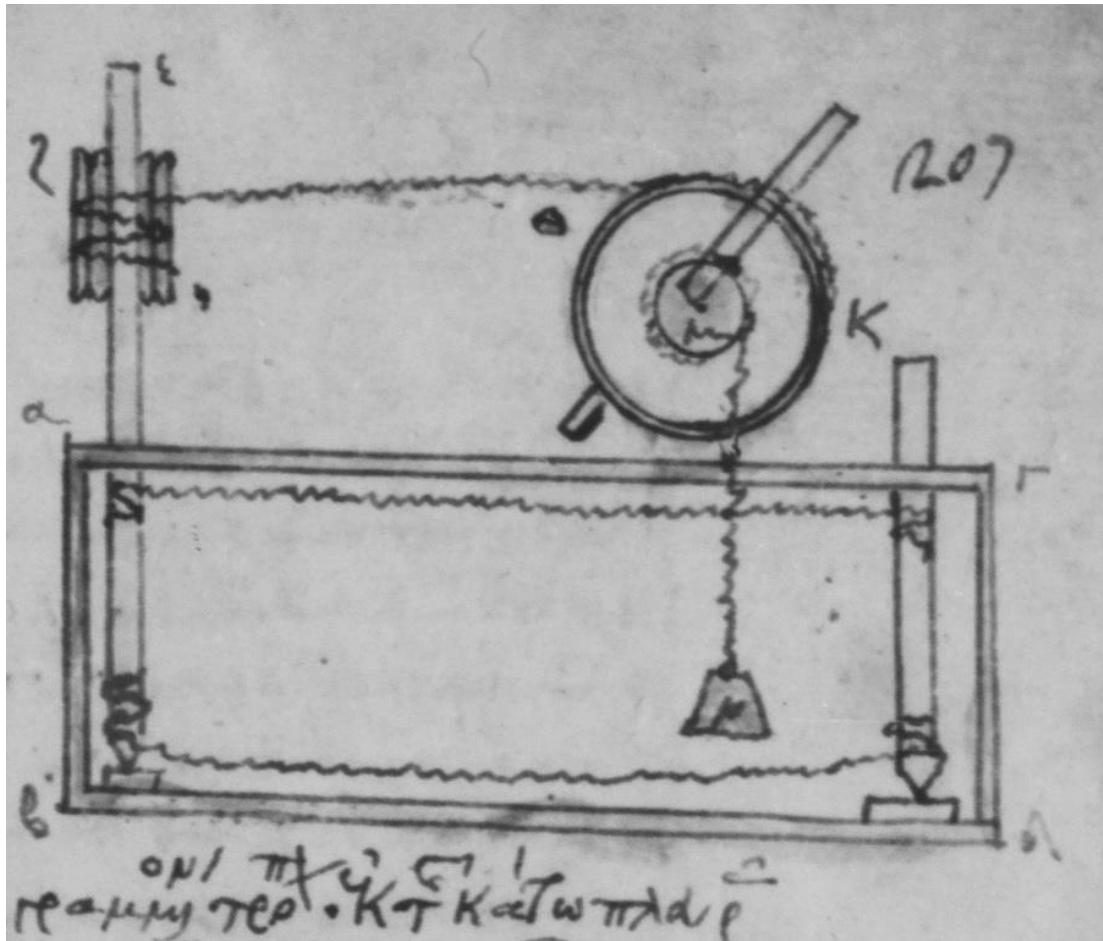


Fig. 30 Papyrus scroll for sailing ships (front view).
A, f. 207^r.

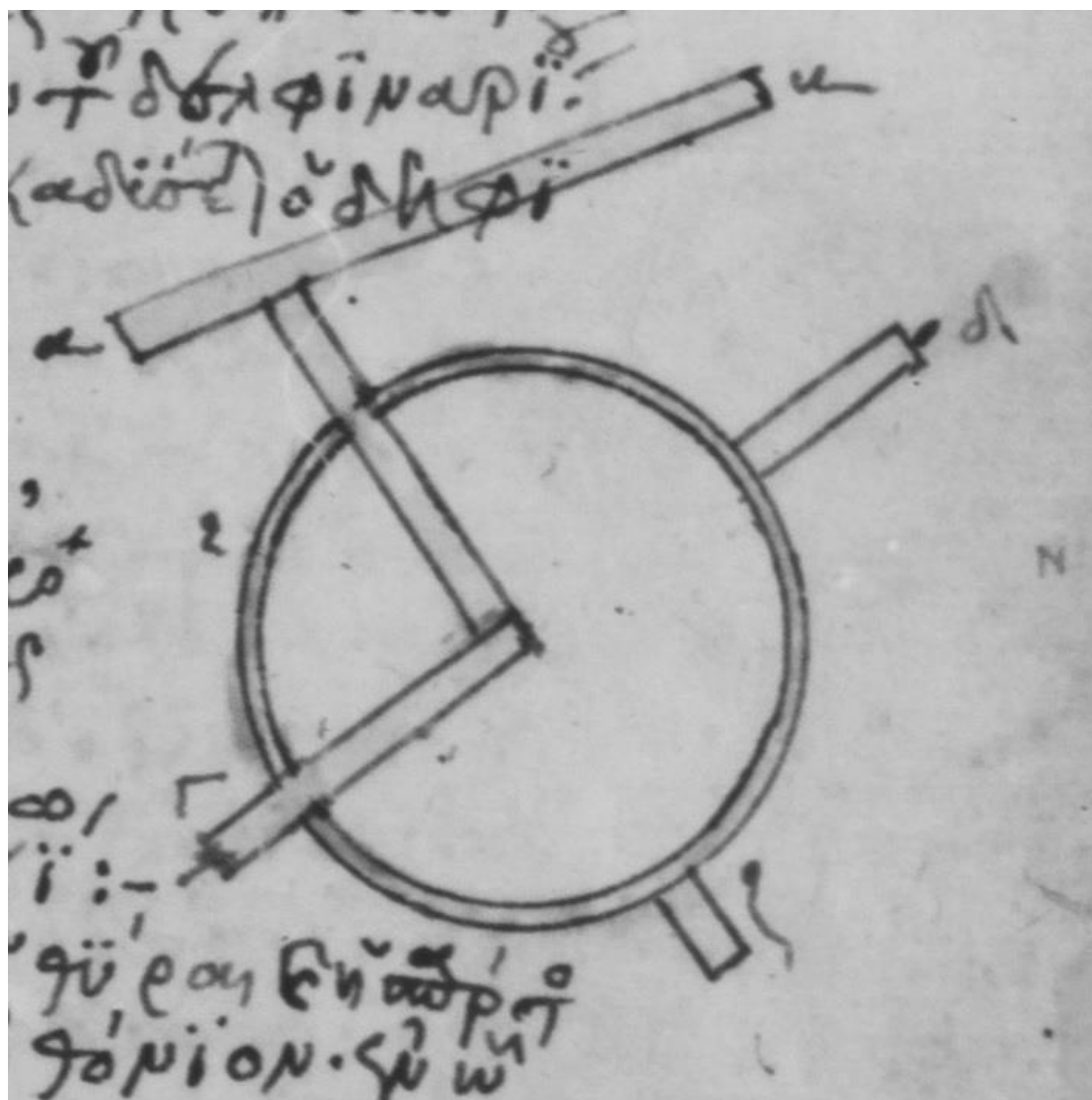


Fig. 31 Axle and pulley assembly for plunging dolphin (plan view).
A, f.207^r.

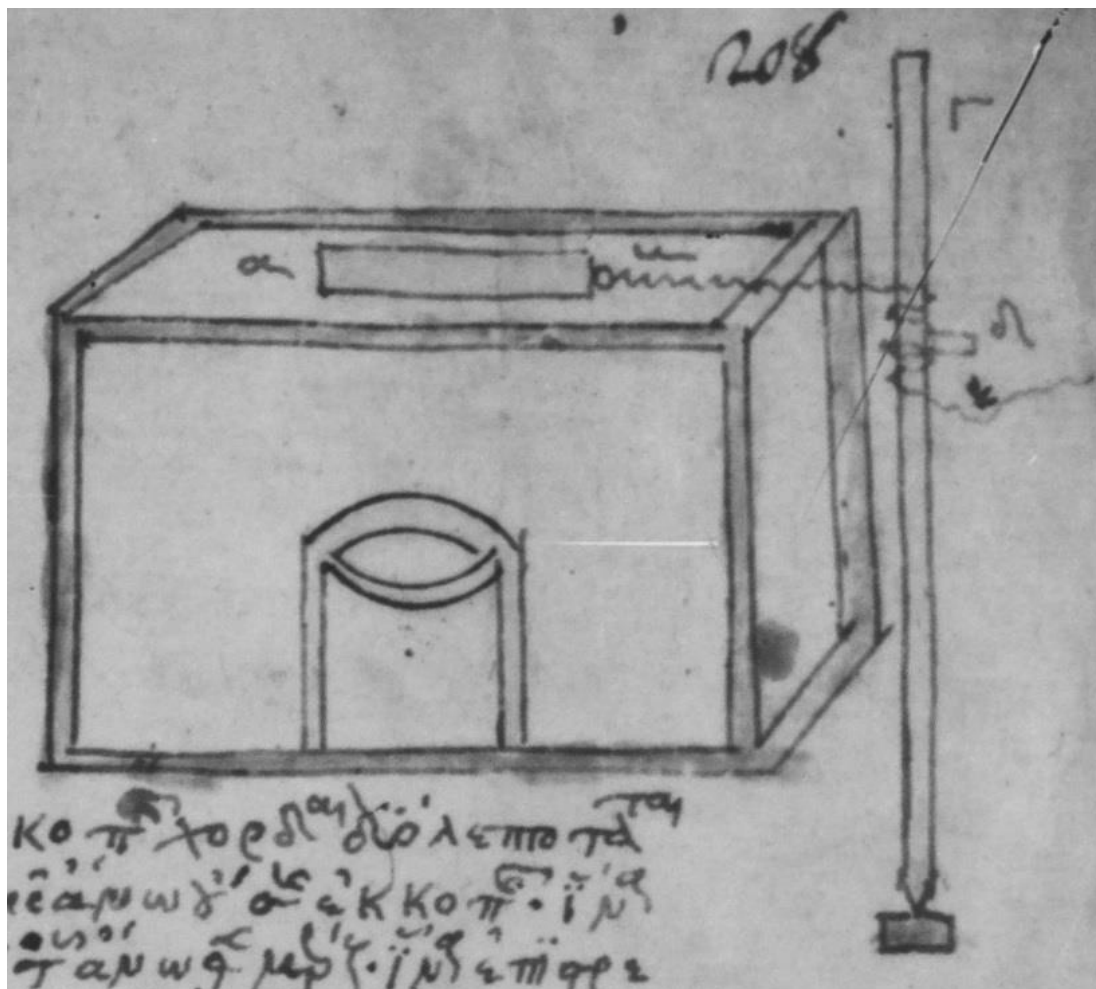


Fig. 32 Mechanism for Nauplius' torch (front view). A, f. 208^r.

APPENDIX 5. SOME CONSIDERATIONS ON MASIÀ (2015)

In the following section, I outline the main argument of Masià's fairly recent article "On dating Hero of Alexandria", *AHES* 69.3 (2015) 231-255, and I discuss its implications for the question of Hero's date. I then summarise the main problems that I have identified with this article. For the sake of clarity, I have divided my account into sections, and I am grateful to Enrico Bellazzecca, PhD candidate in Social Sciences at the Yunus Centre for Social Business and Health, Glasgow Caledonian University, for helping me with the statistical analysis in Masià's article (see section (C) below). A detailed evaluation of, and engagement with, Masià's arguments are essential not only owing to the recent date of publication of his article but also because it is, I would argue, less reliable than it has been thought to be so far.

Masià discusses the evidential value of the eclipse mentioned in *Dioptr.* ch. 35 for the purposes of dating Hero. Masià's main argument is that the eclipse of *Dioptr.* ch. 35 was invented as an example and, therefore, that it cannot be used to determine Hero's life. He does not exclude the possibility that the eclipse data were derived from actual observation, astronomical records (whether reworked or not) and/or invention (any combination of these is possible, according to Masià), but stresses that there are no arguments supporting the thesis that Hero observed the eclipse.¹ The implication of Masià's argument, which is evident throughout his discussion, is that we do not actually know with any certainty Hero's date. He (p. 246) refers the reader to Acerbi-Vitrac's (2014) edition of Hero's *Metrika* for a discussion of the other (internal) pieces of evidence on Hero's date and accepts two possible intervals within which Hero lived, that is, to use his own words, a maximal interval (200 BCE – 350 CE) and a minimal but quite plausible interval (50 BCE – 200 CE).

Masià's article is problematic on many levels. After a brief introduction, Masià (1) discusses how time was expressed in ancient Greek (esp. in Greek astronomy) and how we refer to ancient dates (pp. 233-40), (2) gives a (questionable) interpretation of *Dioptr.* ch. 35, along with some information on

¹ Masià (2015: 244, 252). He does not, however, cite any arguments supporting the thesis that Hero did not observe the eclipse.

actual eclipses that (in his view) fit his interpretation (pp. 240-46) and, finally, (3) derives from the interpretation of the text a ‘simple probabilistic model’,² which he uses to calculate the probability that an eclipse happened under the conditions given by the text and in a period of time coinciding with the suggested timeframes for Hero’s life (pp. 246-52). He then concludes his discussion by choosing a particular combination of ‘parameters’³ as the most plausible (however, he does not justify his choice of this combination) and by saying that what he has adopted is not a ‘confirmative methodology’ (pp. 252-54). He expressly states (p. 253) that he does not wish to refute or confirm any particular hypothesis and that he is just presenting ‘facts’ and assessing them, in some cases associating them with some probabilities.

I have identified a number of problems with this argument, which I summarise in the following sections: **(A)** interpretation of *Dioptr.* ch. 35; **(B)** (calculation) errors and inconsistencies; **(C)** statistical analysis.

(A) Interpretation of *Dioptr.* ch. 35. The main problems here concern the constitution and translation of the text.

(1) Masià discusses the restitution of the article in the following sentences: (a) τετηρήσθω οὖν ἔν τε Ἀλεξανδρείᾳ καὶ Ῥώμῃ <ῆ> αὐτὴ ἔκλειψις τῆς σελήνης (*Dioptr.* 302.17-18) and, later on in the text, (b) ἔστω οὖν εὐρημένη ἐν τοῖς εἰρημένοις κλίμασιν αὕτη <ῆ> ἔκλειψις, ἐν Ἀλεξανδρείᾳ μὲν νυκτὸς ὥρας ε, ἐν Ῥώμῃ δὲ ἡ αὐτὴ νυκτὸς ὥρας γ (*Dioptr.* 302.22-5).⁴ He accepts the first supplement but rejects the second, essentially because ‘it is surprising that in a document with so few article restitutions [i.e. the *Dioptra*], there are two such errors so close’ (p. 241).⁵ He argues that in both cases the reference is to an indeterminate eclipse in view of the fact that the whole passage is formulated in mathematical style and that the second supplement is unnecessary.⁶

² The meaning of this phrase is unclear to me.

³ On the problems involved in the use of this term, see section **(C)** below.

⁴ The last part of the sentence is corrupt in the manuscripts: δὲ ἐν αὐτῆς νυκτος ωρας τρεῖς.

⁵ In a footnote (p. 241 n. 27), he says that the Greek αὕτη ἔκλειψις (misspelled as ἔχλειψις) is correct, which is equally perplexing.

⁶ In another footnote (pp. 241-2 n. 29), he gives a number of examples of the neutralisation of the semantic opposition ‘definite/indefinite’ in Greek mathematics, but the passages that he cites are not parallel passages.

(2) Masià says that in the passage there is an ‘articulation’ – does he mean alternation? – of the verbs ‘to observe’ (τηρεῖν) and ‘to find’ (εὐρίσκειν), and that in sentence (b) the phrase ‘in the records’ must be added to emphasise such articulation (he translates thus: ‘let **an** eclipse be found **<in the records>** – **this one**, in the stated regions: in Alexandria in the fifth hour of the night, and the same one in the third hour in Rome’). The reason for his supplement is that ‘the sentence “to find an eclipse in the stated regions” sounds a bit strange in Greek, and it is much more reasonable to repeat the complement of the same verb where the verb last appeared’ (p. 242 n. 31, with no further explanation). This understanding of the text leads Masià to suppose that Hero found the eclipse data in an astronomical record (p. 242), which contrasts with his main line of argument. Another, perhaps more significant, problem has to do with Masià’s adherence to the Greek text. It is unclear whether Masià adheres closely to the text (and hence to the eclipse data given in the text) or not, although he seems to end up preferring a looser interpretation. His looser interpretation does not take into account the eclipse data for Rome, but he does not substantiate this choice. Furthermore, it is the looser interpretation, not the stricter one, that is adopted in the probabilistic analysis, and Masià (p. 245 n. 43) states that in the probabilistic section of his paper he will assess statistically the consequences of this interpretation, even if he has not found any indication to support it. Why, then, choose such an interpretation?

(B) (Calculation) errors and inconsistencies. I have found throughout Masià’s article a number of errors, inaccuracies and inconsistencies. There are two main inconsistencies. First, in his interpretation of the text the author chooses the 2013 times of the sunset to calculate the beginning of the night, whereas in his probabilistic analysis he chooses the 2012 times.⁷ Second, the author’s attitude towards margins of error is inconsistent. For example, he seems to tolerate the fact that the time difference between Alexandria and Rome as inferred from the text is a ‘raw approximation’ (that is, between one and three

⁷ Both choices contrast with his statement that ‘the nocturnal hour of a particular place should be deduced from the UTC time zone, the hour of the sunset in this place on that particular night and the duration of that night’ (p. 235); what immediately follows is unclear: ‘[t]he hour of the sunset must be exact and *not related to the time zone*’ (my emphasis).

hours, following his calculations), but he does not accept similar margins of error in the case of the correspondence between the eclipse data from the text and the actual eclipse of 13 March 62 CE.⁸ What is more important, however, is that the author's calculations for the eclipse data given in the text seem to be incorrect. He states (p. 243) that '[i]f we assume that the night starts at 18:07 in Alexandria and at 18:14 in Rome, and calculate the exact nocturnal hours, an eclipse observed between 22:09 and 22:17 in Alexandria would be observed between 21:09 and 21:17 in Rome. In Alexandria, this is the fifth nocturnal hour, whereas in Rome this is the third nocturnal hour'. If I understand the argument here correctly, the intervals given do not correspond to whole nocturnal hours,⁹ and hence Masià's claim that the time of the eclipse of 62 CE as observed in Alexandria at 22:39 does not fit the interval he has given is pointless.¹⁰ More generally, the fundamental problem seems to be that, if we do not know the time of the sunset in Alexandria and in Rome on 13 March 62 CE, we cannot say whether and to what extent the eclipse of 62 CE does not fit Hero's data. Masià (p. 244 n. 39) remarks that 'our ignorance of the exact time of sunset in Alexandria and Rome on that day introduces *uncertainties that cannot be estimated*' (my emphasis). What, then, is the point of his study?

(C) Statistical analysis. In addition to the fact that the 'key criterion' (KC) for associating a triad (nocturnal hour, day, month) to an eclipse that actually happened within the chosen timeframes for Hero's life is derived from a

⁸ As Masià (p. 234 n. 9) notes, the eclipse is sometimes recorded as having occurred on 14 March. This depends on the use of the Terrestrial Dynamical Time (TDT or TD) or Terrestrial Time (TT), a modern astronomical standard first introduced in 1976 for time measurements of astronomical observations made from the surface of the Earth. TT does not take into account the irregularities in the rotation of the Earth and can be used, among other things, to calculate the so-called TD of Greatest Eclipse, namely, 'the instant when the center of the Moon passes closest to the axis of the Earth's umbral shadow' (NASA 2016). On TT, see IAU Resolutions (2000) s.v. Resolution B1.9.

⁹ Masià (p. 243 n. 37) observes that on March 13 nocturnal hours are almost one hour long.

¹⁰ Masià takes the time of the eclipse as observed in Alexandria from the NASA tables (NASA 2016). It is important to note that $22:39 - 22:17 = 00:22$. As Masià himself reminds us (p. 239 n. 23), the mean error in the eclipse observations made by Greek astronomers and recorded in Ptolemy's *Almagest* is $-00:23$ hours. See esp. Ptol. *Alm.* 4.6 = 314.16-315.12 Heiberg, with Steele (2000: 103-4).

loose interpretation of the text (see above under (A)),¹¹ I have identified the following problems. The author does not specify:

(1) the statistical model(s) that has/have been used – ‘simple probabilistic model/framework’ could mean anything;¹²

(2) the estimators, that is, how the data have been treated and how the model(s) fits/fit the data;

(3) what the data distribution looks like (this is important because it affects the type of analysis that can be carried out; if the data distribution is not normal, the data should be either normalised or modelled through other techniques that deal with non-normal distribution in order to draw statistical inferences);¹³

(4) the robustness checks, that is, how the author has validated his analysis and findings.

There are also problems with the parameters. First of all, the so-called parameters ‘scenario’ and ‘framework’ are not parameters.¹⁴ The scenario is

¹¹ The key criterion appears to be that ‘[t]he triad must have a nonzero intersection with the period from the beginning to the end of the eclipse’ (p. 247). Masià does not explain what a ‘non-zero intersection’ is, but presumably means that the data must be significantly different from zero. Since the exact day of the eclipse of 62 CE cannot be inferred from *Dioptra* ch. 35 with any degree of accuracy (the eclipse is said to have occurred 10 days before the vernal equinox, but we do not know when Hero or his source started counting the days), Masià accepts a margin of error of one day. This introduces an ‘extended key criterion’ (EKC), which Masià (p. 248) defines as follows: [t]he triad must fit some instant between the beginning and the end of an eclipse that actually happened, or of an eclipse that actually happened exactly 1 day before or exactly 1 day after’. He performs his calculations according to both criteria.

¹² Did he employ, for instance, linear regressions, vector autoregressive models or hierarchical models? On econometric modelling, see Dougherty (2011: 83-530).

¹³ Normalisation (i.e. scaling of variables) is risky because it may yield spurious data, but nonetheless it is an acceptable practice depending on the nature of the data. See Härdle-Simar (2015: 135-7).

¹⁴ For Masià (p. 248), the ‘scenario’ is ‘[t]he length of the time interval, measured in years, in which Hero’s life span is entirely included’. He identifies two scenarios, a maximal scenario (– 200, + 350) and a minimal scenario (– 50, + 200), which correspond, respectively, to the maximal interval and the minimal interval mentioned above. Each scenario admits of two ‘frameworks’, namely ‘the intervals within which the observed eclipses are recorded’ (p. 248). The first framework, which is associated with KC, ‘exactly matches the scenario’, whereas the second framework ‘extends the lower limit of the scenario [i.e. applies EKC], including the possibility that the eclipse could be drawn from an almanac’ (p. 248). It is unclear to me how the framework differs from the scenario.

nothing more than a scenario (this applies, by extension, to frameworks 1 and 2). Second, the author (p. 248) states that the eclipse of 62 CE is unique over a long period of time. As a result, he imposes the following restriction: '[i]n the triad's hour, the eclipse must be unique among all registered eclipses'. He calls this restriction 'uniqueness'. It is unclear what this parameter means. Additional problems include: (1) why does the author not take into account the year during which an eclipse has occurred? (reason not explained); (2) non-zero intersection seems to mean that the data must be significantly different from zero (cf. above, n. 11), but the author does not say whether the parameter estimates are negative or positive.¹⁵ Overall, it is not clear how we should interpret **Tables 1-4** (pp. 249-51). Did the author employ F statistics in combination with P values to determine the goodness of fit of his model(s)?¹⁶ If he did, we still do not know the statistical significance of his results because we are given neither the P values nor the standard errors relating to the parameters.¹⁷ I would hazard the guess that the author has simply calculated the probability that something has happened (that is, in this particular case, the probability that a randomly chosen triad fits an actually occurred eclipse) but without telling us whether the data fit his model(s).

For all of these reasons, it is difficult to determine whether Masià's analysis has real statistical value.

In my detailed assessment of Masià's article, I have shown that there are several problems with his argument. The purpose and methodology of his study are unclear, and there are many inaccuracies, inconsistencies and errors in his treatment of the eclipse question. His interpretation of *Dioptr.* ch. 35 leaves much to be desired, leaving us to wonder how an actual eclipse record can be considered the result of invention.¹⁸

¹⁵ This allows one to know how the variables are associated.

¹⁶ F statistics are critical values that inform acceptance or rejection of a null hypothesis in statistical inferences. P values indicate the probability that inferential results have (not) occurred by chance. On these indicators, see Dougherty (2011: 145-8).

¹⁷ The standard errors indicate the extent to which the estimators deviate from a standard deviation.

¹⁸ The reader who wishes to look deeper into the eclipse question may refer to Acerbi-Vitrac's (2014: 18-21, 103-115) recent edition and discussion of *Dioptr.* ch. 35 (with further bibliography).

APPENDIX 6. *INDEX TERMINORVM TECHNICORVM*

This index gathers together (a) technical terms (or occasionally phrases), (b) particular occurrences of terms used in a technical sense, and (c) terms which are reminiscent of a technical usage. Terms belonging to category (c) are indicated with a superscript asterisk. Technical terminology here comprises specialised words used in the domains of mechanics, mathematics, philosophy, art criticism, architecture and construction, and the guiding principles for the identification of such terms are monoreferentiality and referential precision (see generally Gotti 2008: 33-7). Some exceptions to these principles include terms which are quite generic but whose specialised meaning can be inferred from the context (for instance κανόνιον). I have deliberately avoided arranging terms into categories according to disciplines because it is often not possible to make a firm distinction between mechanical and architectural terms. References give the page and line numbers of the present edition. Emendations, additions and deletions are indicated by the use of italics.

ἀγκύλη ('loop' of cord) 12.14, 22.5, 22.9, 22.19-20, 44.2, 46.20, 54.3, 78.7, 78.9, 78.11, 86.20, 88.5, 88.7, 88.14; see also ἀγκυλῖναι, ἀγκυλόομαι, ἀπαγκυλόω and προσαγκυλόομαι	ἀπαγκυλόω ('make a loop in' a cord) 98.20-21; see also ἀγκύλη, ἀγκυλῖναι, ἀγκυλόομαι and προσαγκυλόομαι
ἀγκυλῖναι ('loops' of cord) 78.8; see also ἀγκύλη, ἀγκυλόομαι, ἀπαγκυλόω and προσαγκυλόομαι	ἀποδίδομι ('attach'; Med., 'pass', 'extend') 22.14, 24.3, 24.14, 36.16, 38.19, 42.18, 42.21, 46.21, 48.17, 50.9, 54.21, 56.3, 56.12, 56.20, 58.14, 58.16, 60.7, 60.16, 62.6, 84.4, 88.11, 94.7, 96.7, 96.9, 100.1
ἀγκυλόομαι ('to be looped', of cord) 84.8; see also ἀγκύλη, ἀγκυλῖναι, ἀπαγκυλόω and προσαγκυλόομαι	ἀποκαθίστημι* ('return full circle') 50.5
ἀετός ('pediment') 100.18	ἀπολαμβάνω ('secure') 76.7-8, 76.12, 86.21

- ἀποπορεία ('backward motion' of mobile automaton) 20.9, 20.14, 22.22, 24.8, 24.10, 30.7, 42.9, 60.10, 60.18, 62.19; see also πορεία
- βάσις ('base' of cone) 28.4, 28.8
- βεβηκώς ('standing', of cone) 28.12
- γίγγλυμος ('hinge') 64.17
- γόμφοι ('dowels') 34.9
- γομφωτήρια ('tenons') 98.5; see also ἔκκοπή
- διάθεσις ('arrangement', 'disposition' of figures) 2.19, 4.4, 4.6, 70.10, 80.5; (mechanical 'arrangement', 'configuration') 6.4, 64.12
- διάμετρος ('diameter') 26.9, 26.16; see also κατὰ διάμετρον
- διαμηρύομαι ('to be arranged in hanks', of cord) 34.16, 42.6, 56.7
- διάπηγμα ('partition') 40.9, 40.13; see also διάφραγμα
- διαρρινάω ('file down') 88.3; see also περιρρινέω
- διαστήματα ('radii' of circle) 60.5
- διάφραγμα ('partition') 46.6, 52.3, 56.15-16, 60.13, 60.15; see also διάπηγμα and διαφράσσομαι
- διαφράσσομαι ('to be partitioned') 60.12-13; see also διάφραγμα
- δίχα τέμνομαι/τέμνομαι...δίχα ('to be bisected') 26.15, 28.13-15; see also διχοτομία
- διχοτομία ('point of bisection') 26.10; see also δίχα τέμνομαι
- ἐκβάλλομαι ('to be generated', of geom. figure) 28.14
- ἐκκοπή ('notch', 'mortise') 34.6, 98.12-13, 98.18, 106.8, 106.11, 106.13-14, 106.18, 108.3-4; see also γομφωτήρια
- ἔλιξ ('thread' of screw) 34.11
- ἐμπυελίδες ('sockets') 8.6; see also ἐμπυελίδια and πυελίς
- ἐμπυελίδια ('sockets') 32.21, 32.22-34.1, 40.10, 90.19; see also ἐμπυελίδες and πυελίς
- ἐνιλέομαι ('to be screwed on') 34.8, 34.9
- ἐνέργεια ('actualisation') 6.7; cf. 4.20 ('mechanism', 'action')
- ἐντεταμένος* ('stretched', of surface) 16.9
- ἐντορνεύομαι ('to be turned on the lathe') 54.16-17; see also ἔντορνος, τετορνευμένος and τórνος
- ἔντορνος ('turned on the lathe') 90.19; see also ἐντορνεύομαι, τετορνευμένος and τórνος
- ἐξαπτύω* ('string', of automaton) 10.1-2

- ἐξελίκτρα ('bobbin', lit. 'unwinder')
 22.2, 22.10-10, 22.17, 24.1,
 24.3, 24.14, 26.2-3, 26.21,
 94.20, 96.6, 100.13-14, 102.2
 ἐπιζεύγνυμαι ('to be joined', of
 lines) 26.11
 ἐπικράτησις ('prevalence') 30.1
 ἐπίπεδος ('plane') 28.4, 28.12,
 28.14
 ἐπιπορεία ('forward motion', of
 mobile automaton) 60.10,
 60.17; see also πορεία
 ἐπιτόνιον ('plug', of stopcock)
 46.19, 46.22, 48.9; see also
 κλείς
 εὐθεῖα ('straight line', of geom.
 figure) 60.14; cf. 20.13, 20.18,
 36.19, 36.27, 38.5, 40.2
 εὐθύγραμμος ('rectilinear', of
 figure) 36.3
 ἡ ἐκ τοῦ κέντρου ('radius' of circle)
 28.5; see also κέντρον
 ἡμικύκλιον ('semicircle') 28.16-17,
 28.18, 28.20, 28.21, 48.1
 ἡμιτόνιον ('half-spring' of catapult)
 10.8
 θωράκιον ('parapet', in mobile
 automaton) 52.9, 52.10, 52.11,
 52.15, 52.16, 52.18, 52.19,
 52.22, 54.22; ('enclosure', in
 stationary automaton) 74.11,
 74.16, 98.4, 98.6, 98.18, 100.4,
 104.23-24, 106.13
 ἰσόπλευρος ('equilateral') 90.15
 ἰσορροπέω ('to be in equilibrium')
 26.19; see also ἰσόρροπος
 ἰσόρροπος ('in equilibrium') 28.13;
 see also ἰσορροπέω
 ἰσοσκελῆς ('isosceles', of cones)
 28.10
 ἰσχάριον ('joint') 104.22, 106.2
 ἵτς* ('ring') 54.14, 56.5, 56.10
 κανόνιον ('bar-frame') 34.1^{bis}, 34.3,
 34.5, 34.7, 34.9, 34.13, 34.18
 κατὰ διάμετρον ('diametrically
 opposite') 48.3
 κεφαλαί ('capitals') 16.2; see also
 κεφάλια
 κεφάλια ('capitals') 16.2; see also
 κεφαλαί
 κέντρον ('centre' of circle) 26.8,
 28.5, 28.6; see also ἡ ἐκ τοῦ
 κέντρου
 κλειθρίον ('slide') 32.8, 32.12,
 32.14, 50.21, 52.6, 62.1, 62.4,
 62.12, 62.15, 62.19
 κλείς ('tap', 'stopcock') 46.18, 48.9;
 see also ἐπιτόνιον
 κνώδαξ ('pivot' for wheel) 8.5,
 20.19, 26.19, 32.21, 34.19,
 36.7-8, 40.7, 40.11, 40.14,
 40.15-16, 42.8, 48.16, 58.11;
 see also χοινικίς
 κόραξ ('hook') 54.2, 54.3, 54.4

- κορυφή ('vertex' of cone) 28.6, 28.8, 28.11, 28.20-21, 28.21, 28.24
- κοχλίας ('screw') 34.10, 34.11, 34.12, 34.15, 34.20
- κύκλος ('circle') 12.19, 26.7, 28.2, 28.5, 28.7, 28.8, 28.10, 28.18, 60.2, 60.7; cf. 20.15, 26.6
- κυμάτιον ('moulding') 14.18-19, 16.6-7
- κῶνος ('cone') 28.4, 28.6, 28.8, 28.10, 28.12
- λεία ('counterweight') 10.10, 12.1, 12.6, 12.11, 12.16, 14.6, 24.3, 24.4, 24.15, 26.4, 32.3, 32.6, 36.16, 36.17, 36.24, 38.19, 42.21, 42.22, 46.21, 56.3, 56.11, 56.14, 56.20, 58.17, 60.1, 60.7, 60.16, 60.17, 62.7, 62.14, 76.2, 78.3, 78.7, 78.18, 82.7, 82.15, 82.19, 82.20, 84.5^{bis}, 88.12, 94.15, 96.9, 96.12, 100.2, 104.10; see also σήκωμα
- μεσολαβέω ('take in the middle', of wheel) 40.18, 42.3
- μηρύματα ('hanks' of cord) 14.4, 24.20, 38.4, 38.7-8; see also μηρυμάτιον and μήρυσμα
- μηρυμάτιον ('hank' of cord) 24.12
- μήρυσμα ('hank' of cord) 36.24
- μολύβδιον ('lead weight') 108.2
- ὀρθογώνιος ('rectangular', of parallelogram) 20.17, 30.3, 36.2
- ὀρθός ('perpendicular') 26.9, 26.15, 28.14, 66.1; see also πρὸς ὀρθάς
- παραλληλόγραμμον ('parallelogram') 20.16-17, 30.3, 30.19, 30.21-22, 30.24, 36.2
- παράλληλος ('parallel', of line) 26.13
- παραστάς ('pilaster') 90.13; ('doorjamb') 94.3; see also παραστάδιον
- παραστάδιον ('doorjamb') 94.6
- παραχαλασμάτιον ('slack' of cord) 78.15; see also χάλασμα and χαλασμάτιον
- πελεκίνος ('dovetail') 34.1, 34.4
- περιρρινέω ('file down') 98.8; see also διαρρινάω
- περιστύλιον ('peristyle') 52.7
- περιφέρεια ('arc' of semicircle) 48.1-2, 54.16
- πλευρά ('side' of cone [i.e. generatrix]) 28.6, 28.13, 28.14; cf. 22.6, 30.19, 30.22
- πλινθίον ('case' of mobile automaton) 10.19, 12.3, 14.5, 20.15, 20.19, 20.21, 22.8, 22.13, 22.19, 24.5, 24.8-9, 24.9, 24.17, 26.1, 26.2, 26.7, 26.13, 26.19, 28.3, 30.4, 30.5, 30.16,

- 30.20, 30.22, 30.24, 32.4, 32.11, 32.13, 32.15, 32.16-17, 32.22, 34.2, 34.5, 34.8, 34.17, 34.24, 36.1, 36.6, 36.9, 36.19, 36.26, 36.27, 38.2, 38.6, 38.10, 38.13, 38.16, 38.20, 38.23, 40.2, 40.5, 40.8, 40.13-14, 42.1, 42.2, 42.6-7, 42.9-10, 44.8, 56.23, 58.6, 62.3, 62.5, 62.8, 62.10, 62.16, 62.18; ('frame' of stationary automaton) 74.7, 74.10, 74.11, 86.4, 86.9, 86.16, 88.3, 92.3, 98.3, 102.7-8, 106.9
- πορεία ('forward motion', 'journey' of mobile automaton) 12.3-4, 20.8, 20.13, 22.21, 26.6, 30.3, 30.7, 30.16, 32.1, 34.24, 36.3, 42.7, 42.9, 42.11, 42.22, 44.22, 56.23, 58.3, 58.23-24, 60.4, 60.9, 60.11, 110.12; see also ἐπιπορεία
- προσαγκυλόμαι ('to be looped', 'fastened with a loop', of cord) 10.13-14, 12.4-5, 14.8; see also ἀγκύλη, ἀγκυλῖναι, ἀγκυλόομαι and ἀπαγκυλόω
- πρὸς ὀρθάς ('perpendicularly', 'at right angles') 22.12, 100.3, 100.4; see also ὀρθός
- προωσμός ('forward propulsion') 30.1
- πτερύγια ('wings') 102.1
- πυελίς ('socket') 8.25, 20.20; see also ἐμπυελίδες and ἐμπυελίδια
- πυργίον ('small cupola') 16.8-9, 18.13
- σαμβύκαι ('sambucas' [*sc.* musical instruments]) 106.12
- σήκωμα ('counterbalance') 104.22; see also λεία
- σημεῖον ('point' of geom. figure) 26.20, 28.9
- σπειρίον ('base-moulding') 16.1
- στατόν ('stationary (automaton)') 2.16, 4.20, 6.7, 12.10, 20.4, 64.1, 64.7; see also ὕπαγον
- στρογγυλόγλυφος ('with rounded carvings') 90.4
- στροφεῖς (door 'pivots') 74.13, 74.17, 74.18, 76.3, 76.4, 76.5, 76.15, 90.11, 98.4
- στροφωμάτια ('hinges') 52.22
- στυλοβάτης ('stylobate') 54.11, 54.14
- σύριγξ ('tube') 12.6, 12.8, 12.11, 22.12, 22.14, 22.15, 22.16, 26.2, 26.3, 32.4, 32.5, 32.7, 36.16, 56.14, 56.15, 58.1, 58.16-17, 58.19, 60.12, 60.13, 60.17, 60.20, 76.2, 78.6
- συσμηρίζομαι ('to be fitted tightly together') 8.8, 46.8
- σφίγμα ('jamming') 8.11
- σχαστηρία ('trigger') 50.11, 50.12; see also χεῖρ

- τετορνευμένος ('turned on the lathe') 94.20, 96.2; see also ἐντορνεύομαι, ἔντορνος and τόρνος
- τετράστυλον ('tetrastyle') 52.10
- τόρνος ('lathe') 36.9, 36.12; see also ἐντορνεύομαι, ἔντορνος and τετορνευμένος
- τρίγλυφοι ('triglyphs') 100.12
- τροχίλος ('pulley') 22.13-14, 48.17, 48.18, 50.8, 54.21, 56.21, 58.16, 98.21-100.1
- τύλος (wooden 'block') 34.8, 34.11, 34.13
- ὑπαγον ('mobile (automaton)') 2.15, 4.22, 6.3, 6.17-18, 10.8-9, 10.18, 12.8, 20.4, 64.2, 68.5, 70.3; see also στατόν
- ὑπερθύριον ('lintel') 94.7; see also ὑπέρθυρον
- ὑπέρθυρον ('lintel') 90.3, 106.18-19, 106.19; see also ὑπερθύριον
- ὑποσανίδιον ('underside of board') 108.6
- ὑσπλήγγιον (*hysplēngion* [*sc.* 'bar']) 82.13, 82.14, 82.17, 82.18, 94.21; see also ὕσπληγξ
- ὕσπληγξ (*hysplēnx* [*sc.* 'trigger board']) 10.6^{bis}, 10.9, 12.1, 12.3; (= *hysplēngion*) 82.16, 84.6; see also ὑσπλήγγιον
- χάλασμα ('slack' of cord) 14.3, 14.4, 14.6, 32.2, 34.16, 34.21, 36.21-22, 36.24, 38.1, 38.12, 38.18-19, 38.21, 38.24-40.1, 42.5, 44.12, 46.20, 56.6-7, 56.8, 62.9, 62.14; see also παραχαλασμάτιον and χαλασμάτιον
- χαλασμάτιον ('slack' of cord) 32.15, 62.7; see also παραχαλασμάτιον and χάλασμα
- χείρ ('claw') 50.10; see also σχαστηρία
- χοινικίς ('collar') 8.7; (wheel 'hub') 36.10, 36.13, 36.15, 36.18, 36.24, 38.15, 38.17, 38.22, 40.3; see also κνώδαξ

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