Footnotes for *The Scientist in the Early Roman Empire*

This document is organized as follows. Each chapter and section is designated and titled, after which footnotes are given as in the text, with the same numeration as in the printed edition, and sometimes with some contextual markers added so you have an idea of what content the note was attached to, if it's not already clear. Scholarship is cited by author and year. These can be located in the online Bibliography file also linked at www.richardcarrier.info/bibliographies. At the end of this document are also the Appendixes, which were not fully read in the Audiobook.

Chapter One

Section 1.1 "The Problem"

1. Not even in China saw comparable scientific development (despite comparable technological development): cf. Lloyd 1996a and 2002.

2. For the best and most complete discussion of the options for why and when the Scientific Revolution happened, including the examples given in the text and more, see Cohen 1994, who surveys a diverse range of scholarship on the issue. For examples of recent individual treatments of the Scientific Revolution, synthesizing a diverse range of theories, see Henry 2008 and Shapin 1996 (especially in light of Collins 1998: 523–69). For defenses of the very idea of a Scientific Revolution see Yerxa 2007.

3. Inventions relating to the Scientific Revolution: Telescope: Sluiter 1997 and Van Helden 1977 (though obsolete but still useful is C.J. Singer 1921, who also treats the parallel history of the microscope, more thoroughly discussed in Disney et al. 1928 and Ford 1985). Printing press: Kapr 1996 and Eisenstein 1980. New World: Phillips & Phillips 1992 and Barrera-Osorio 2006. Compass: Aczel 2001 and Kreutz 1973. Gunpowder: Partington 1960 and Kelly 2004. All these studies exhibit the general trends noted, but for a broader picture see P. Smith 2004 and 2006.

4. Cohen 1994, esp. §4.2 "Why Did the Scientific Revolution Not Take Place in Ancient Greece?" (pp. 241–60).

5. Quotations assembled of Lloyd 1973: 178, 176, 170, 174.

6. Quotation of Edelstein 1952: 598–99.

7. On ancient education: See my book *Science Education in the Early Roman Empire* (= Carrier 2016).

8. Cohen 1994: 257–59, in respect to Ben-David's elaboration of Lloyd's thesis. I discuss this further in chapter 5.2.

9. Defensiveness in ancient treatises: Edelstein 1952: 600; one need only skim the works of Copernicus, Gilbert, Bacon, and Galileo to find them packed with essentially the same defensiveness—in fact, arguably more so.

10. For instance, this is shown (using Vitruvius as an example) in J.-M. André 1987 and (with a variety of examples) in Barton 1994a. For a detailed analysis of the structure and intent of science writing in antiquity, see Asper 2007.

11. Lloyd even argues etc. in 1990 and 2001: 202–07.

12. The number of published research scientists in any given generation in antiquity is estimated at around a hundred (which would mean there were at least five hundred over the three centuries of the early Roman empire): see Carrier, *Science Education* (2016), pp. 29–31.

13. Growing but easy to kill: I will discuss this in chapters 2.5 and 5.3.

14. Ben-David 1991: 301.

15. Ben-David 1984: 31.

16. Archimedes codex: Netz & Noel 2007.

17. Bacon 2001: 3–42 (quotes from 5 and 10; opposition from priests, aristocrats, and scholars: 5–38; religious relevance: 38–43; political, military and economic utility: 43–56; moral value: 57–62). Though this was originally published in 1605, I cite the modern edition for convenience. An excellent discussion of the context of a broader Christian condemnation of 'curiosity' against which Bacon is arguing is provided in P. Harrison 2001; and Neil 2004: 99–138, concluding, "on the whole" Christian institutions "condemned curiosity" and resisted efforts to rehabilitate it even in the 17th century (ibid., p. 157). And on Christian (not necessarily religious) hostility to science and scientists during the 17th century, which was arguably more severe than any non-Christian hostility known in Roman times, see Lougee 1972 (esp. pp. 45–60) and Crouch 1975 (esp. pp. 37–90).

18. Ben-David 1984: 39.

19. This is the entire thrust of his argument in Ben-David 1984: 39–44.

20. Jane Austen, *Sense and Sensibility* 1811, vol. 1, chapter 19 (= Austen 1996: 92–93).

21. D. Lee 1973: 70–71; Carrier 2016: 8. Even Peter Green, who otherwise makes much of finding this aristocratic attitude in antiquity, nevertheless admits it can be found in every era, even in the 18th century writings of David Hume: P. Green 1990: 470–73 (cf. 470) and 855 (notes 38 and 39). For another example and further discussion see chapter 4.6.I.

22. Music: M. Clarke 1971: 52–53. On music education in antiquity, see Carrier 2016 (index).

23. Art: Blagg 1987; Rawson 1985: 88–89. See also chapter 3.8.I.

24. For what I mean by "upper" and "middle" class in Roman society see chapter 4.6.

25. On the breakdown of Church power and authority as a necessary step toward the Scientific Revolution see P. Harrison 1998.

26. Attempts to argue that science continued unabated during the middle ages are summarized by Stark 2001 and 2005 (and see chapter 5.10). For his survey of medieval 'accomplishments' see Stark 2001: 130–34 and 2005: 38–54. Some are not medieval but in fact ancient (see chapter 3.6). For more detailed attempts to document advances in medieval technology see: L. White 1962 and Gies & Gies 1994 (though both rely on obsolete scholarship and are frequently wrong; e.g. White's conclusions regarding water power are now well refuted: e.g. Walton 2006 and the many sources on ancient water power cited in chapter 3.6). There is a concise but thorough refutation of Stark in Carrier 2010.

27. Nicolaus Copernicus articulated his heliocentric theory during the first half of the 1500's, Tycho Brahe improved astronomical data in the second half of the 1500's, and Johannes Kepler's significant work began in the first decades of the 1600's. Andreas Vesalius started achieving and publishing his improved anatomical results in the middle of the 1500's, William Harvey in the early 1600's. Galileo's work occupied the first third of the 1600's, and he was advancing new and experimental work started by others no earlier than the mid-1500's. William Gilbert completed his own work in the late 1500's and published in 1600. On all these basic details see Henry 2008 and Shapin 1996. Of course some notable contributions were made by Muslims in the interim (e.g. Hill 1993), but these were fleeting, scarce, and of limited significance. Most of the advances they are alleged to have made were actually recoveries of lost ancient knowledge and thus not in fact an example of progress. Likewise, some of John Philopon's commentaries in the 6th century A.D. are claimed as an exception, though he doesn't say he conducted the experiments he refers to, so we can't say for sure that he wasn't just repeating what he'd read in earlier scientific treatises—since he only reproduced conclusions already reached by Strato or Hipparchus long before the days of Ptolemy and Hero (see discussion in chapter 3.4; as noted in Cohen & Drabkin 1948: 217, n. 1, "It is difficult to say to what extent Philoponus is original in these views and to what extent he is recording an anti-Aristotelian tradition"); either way, Philopon's work does not contain any novel physics (indeed, his work is hardly even scientific at all). Philopon's claims were also dismissed or ignored just as Strato's were. In Philopon's case, this might have been due in part to his being declared a heretic; in Strato's case, it might have been due in part to his being an atheist. See discussion in chapter 3.5, with: Russo 2003: 351; Drake 1989; Wolff 1987; *ODCC* 896; *EANS* 436–37 and 765–66; *OCD* 1135 and 1406; *DSB* 7.134–39 and 13.91–95; *NDSB* 4.51–52 and 6.540.

28. Crombie 1959 (even more thoroughly confirmed in Crombie 1994).

29. On the collapse of the Roman political and economic institutions in the 3rd century A.D., and the subsequent rise of Christian power in the 4th century, see Drinkwater 2005; Southern 2001; Michael Grant 1999; Rathbone 1997; Cameron 1993; Brown 1992; MacMullen 1988 (with 1984 and 1997); and Williams 1985. Chapter three will explore the idea that Roman science may have been on the right track just immediately preceding these events. Two plagues also struck (the first in 165–180 A.D. and the second, widely regarded as substantially worse, in 251–266 A.D.) which may have further damaged or disrupted the social and economic system in the 3rd century (see Jackson 1988: 172–73, who estimates losses could have been as high as 25% of the population in each case, though it was probably less).

Section 1.2 "The Focus"

30. Note that I shall employ the traditional convention of B.C. and A.D. in lieu of the culturally neutral B.C.E. and C.E. because the original notation is more familiar and there is no good reason to change it. Both indicate the same division of eras, which was the invention of a Christian and only makes sense as such. Changing the acronyms does nothing to conceal that fact and therefore serves no purpose. Analogously, calling the sixth day of the week 'Saturday' (literally "Saturn's Day") does not entail embrace of a Eurocentric worldview or belief in the God Saturn. It's just clear English.

31. The exact date of publication for the Lucretian poem is debated, but it must have been sometime between 100 and 40 B.C. Before Lucretius, Epicurean natural philosophy had been introduced into Latin more clumsily by Gaius Amafinius, but at any rate, both authors lived through the early 1st century B.C., as did a few other Epicureans writing in Latin. See Rawson 1985: 284; Farrington 1946: 88–91; with *OCD* 67, 291, 863–65 (s.v. "Amafinius, Gaius"; "Catius, Titus"; "Lucretius (Titus Lucretius Carus)"), *DSB* 8.536–39 (s.v. "Lucretius"), and *EANS* 512–13.

32. On the derivation and meaning of the phrase 'Second Sophistic' and on dating when it began and ended, see Bowersock 1974, Anderson 1993, Whitmarsh 2005, and *OCD* 1337–38 (s.v. "Second Sophistic"). For what it involved, especially in respect to Roman science, see von Staden 1995 (using Galen as an example) and Brunt 1994.
33. This point is discussed in more detail in chapter three of Carrier 2016.

34. For a broad yet brief summary of both the differences and similarities see Edelstein 1952. On the problem created by these issues for identifying any premodern activity as 'science' see Sharples 2005: 1–7, Lloyd 1992b and 2004, and Rihll 2002: 7–9, with Dear 2005 and *OCD* 560–81 and 717–18 (s.v. "experiment" and "hypothesis, scientific"). For a more complex approach to defining science (not adopted here): Russo 2003: 15–30. For something simpler: Healy 1999: 100–01. In contrast, there is no use or merit in a complete rejection of modern categorization of the sort voiced in French 1994: ix-xxii (which is aptly criticized in Healy 1999: 115 n. 1).

35. We will summarize Ptolemy's work in chapters 3.3 and 3.4, but on Galen's respect for mathematical method, see relevant discussion and note in chapter 3.6.VI here (and chapter seven of Carrier 2016). On the empiricism and scientific method of both Galen and Ptolemy, see relevant notes and discussions here in chapter three (especially 3.7).

36. *LSG* 1072 (s.v. "*mathê*, *mathêma*" § 1–2; cf. "*mathêmatikos*" § I). This was always the meaning of the Latin word *scientia*, despite being the etymological source of our word "science." In fact, *scientia* was often even broader in connotation, designating any and all knowledge of any kind, cf. *OLD* 1703 (s.v. "*scientia*"). Likewise, words like *ars* or *technê* (designating *any* art, skill, or science that can be articulated systematically), or *epistêmê* and its cognates (designating the epistemologically well grounded knowledge of *any* skill or subject), were also either too broad or too specialized in connotation, even though they also sometimes properly translate as 'science' (see *LSG* 660, s.v. "*epistêmê*," "*epistêmonikos*," "*epistêmos*," etc.; *LSG* 1785, s.v. "*technê*," "*technikos*," "*technitês*," etc.; and, e.g., *OLD* 175, s.v. "*ars*").

37. As in 'scholarly', to be distinguished from the use of "academic" in a modern pejorative sense, or from the completely different use of "Academic" as a proper noun in reference to one of the ancient schools of philosophy.

38. *LSG* 1072 (s.v. "*mathê*, *mathêma*" § 3–4; cf. "*mathêmatikeuomai*" and *"mathêmatikos"* § II.1–2). This was always the meaning of the Latin word *mathematicus*: see *OLD* 1084 (s.v. "*mathematicus*$_1$" and "*mathematicus*$_2$").

39. The same applies to ancient words for 'engineer' (on which see Donderer 1996: 16–24), and one could build a similar case around ancient words for doctor (not always designating a scientific healer) or astronomer (which sometimes meant astrologer).

40. I will demonstrate this in chapter two. But for an introductory discussion of the contrast between *mathematicus* and *physicus* see Russo 2003: 187–94. See also chapter 2.2 and 2.7.

41. Aulus Gellius, *Attic Nights* 1.9.6–7.

42. Aulus Gellius, *Attic Nights* 1.9.8, using (though writing in Latin) the Greek words *atheoretoi*, *amousoi*, *ageometretoi*, meaning "without having observed or contemplated," "without culture or education," and "without a knowledge of geometry," respectively—or in other words, "unprepared, uncouth, and mathematically illiterate." See *LSG* 31–32 (s.v. "*atheôrêtos*"), 85 (s.v. "*amousos*"), and 346 (s.v. "*geômetrêtos*").

43. Study of the nature of ancient natural philosophy as a whole, on its own terms: For examples of such an approach see Lehoux 2012 and French 1994.

44. My position thus does not correspond to any of the stereotyped battlelines in the debate over a so-called "Whig interpretation of history," which is in my view a terrible anachronism (originally having to do with a specific question in the political history of Britain). I follow and agree with the analysis of Brush 1995 and Mayr 1990, that one can validly be presentist and progressivist without being "Whiggish," especially in the history of science.

Section 1.3 "The Method"

45. On the status of intellectual freedom under the Roman empire see Breebaart 1976. On ancient equivalents of universities, and ancient academic societies, see chapter eight of Carrier 2016.

46. For Hypatia see Carrier 2016 (index), with *NDSB* 3.435–37 and *EANS* 423–24. Ironically, active disdain for natural philosophy was more evident in earlier Athenian history than in Roman, e.g. in the satire of Aristophanes' *The Clouds* (see French 1994: 6–10 and Olson 1984), in the fears expressed by Plato (e.g. *Laws* 10.886d-887a) and in the trials of Protagoras, Anaxagoras, and Socrates, which never saw their like again (see A.E. Taylor 1917 and Dodds 1951: 179–206, with Plutarch, *Pericles* 32.3 and *Nicias* 23.2–4, and Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 2.12–14). See also *OCD* 227–28, 465 and 739–40 (s.v. "belief," "Diopeithes, decree of" and "intolerance, intellectual and religious"). Later came the merely threatened prosecution of Aristarchus for the same reason (see P. Green 1990: 186 and Plutarch, On the Face that Appears in the Orb of the Moon 6 (= *Moralia* 923a)). Also dated near the same period would be the (probably mythical) murder of the discoverer of irrational numbers (according to Pappus, *Commentary on Book 10 of Euclid's 'Elements'* 64). But as Edelstein 1952: 589–94 shows, such active interference with scientific freedom was never repeated in pagan antiquity, and as Dover 1976 argues (slightly corrected by O'Sullivan 2008), much of it had already been exaggerated to begin with.

47. On Christian suppression and control of thought and ideology see MacMullen 1984 and 1997 and relevant sections of Hopkins 1998 and Watts 2006. On the evolution of pagan persecution of Christians see Janssen 1979, Hopkins 1998, Rives 1999, and De Ste. Croix 2006 (and for the converse: Salzman 1987). Even pagan persecution of Christians focused more on controlling actions than beliefs, but the involuntary burning of doctrinal books, which begins in the 3rd century, indicates that control of ideology was now on the radar. This contrasts somewhat with the previous, very limited, and sporadic suppression of 'malevolent' (as opposed to benevolent and hence approved) magic and divination, where it was always *behavior* that was the target of control more than thought, speculation, or belief. Even the burning of magical and astrological books was not an attempt to control thought, doctrine, or ideology, but an attempt to eliminate 'dangerous' behavior, such as the production of poisons or claims to supernaturally 'predict' the fate of reigning emperors. On this limited suppression (alongside widespread acceptance) of magic and divination see Ankarloo & Clark 1999: 243–66 and Dickie 2001: 142–61 (on later Christian efforts: 251–72). For astrology see Swan 2004: 280–81, Africa 1967: 73–81, and Barton 1994a: 1–94 and 1994b.

48. Surveys of inscriptions mentioning doctors: Gummerus 1932; Gourevitch 1970; Nutton 1977; Korpela 1987; Meunier 1997; Rémy 2010; and Samama 2003. Scholarship on the social status of doctors (though not always distinguishing the scientifically educated from other *medici*): Scarborough 1970; Kudlien 1976 and 1986; J. André 1987; Horstmanshoff 1990: 187–96; van der Eijk et al. 1995; Nutton 1985, 1995, and 2013: 167–68; Mattern 2008: 21–27; and Israelowich 2015: 11–44. Studies of doctors and medicine in ancient art: Grmek & Gourevitch 1998; Hillert 1990. Medical subjects on ancient coins: Penn 1994. The doctor in ancient literature: Amundsen 1974 and 1977.

49. For example Netz 2002 and the relevant sections of Cuomo 2001 and 2007. R. Taylor 2003: 9–14 and Donderer 1996: 68–76 survey the social status of architects in the Roman period (conclusion: comparable to doctors). Donderer also produces a large number of Roman-era inscriptions mentioning architects or engineers, probably the largest and most complete collection in print. See also Cohon 2010. On the (perhaps lower) social status of surveyors, B. Campbell 2000: xlv-liii.

50. For example: *EANS* 612–24; with: W.H.S. Jones 1947; Sarton 1952: 293–94; Cauderlier 1978; Nutton 1984b: 318; Evans 1998: 345–47; A. Jones 1999; Bagnall 2009: 338–57; Netz 2011. For surveys of medical papyri: Marganne 1981, 1998, 2001; with further discussion in Nicholls 2010. For papyrus fragments of an ancient geographical treatise: Gallazzi & Settis 2006.

51. Archimedes mosaic: For image, summary, and sources: Bol 1983. For discussion of its history and assessment: Goethert 1931 and Paul 1962. Similarly, some claim a gold ring seal depicting an astronomer at work is an ancient representation of Aratus (or Eudoxus or Eratosthenes), but it is more widely regarded as a forgery of the 16th century: Henig 1994: 314–15 (§ 656); vs. Schefold 1997: 296–97, 525–26 (Abb. 173). This judgment was reached for several reasons, including "the unusual subject matter" (vs. the common use of the same motifs in art of the 16th century). There *are* authentically ancient depictions of Aratus, as a poet inspired by Urania (the Muse of Astronomy), but their motifs suggest poetry rather than science is the honored subject: Schefold 1997: 286–89, 418, 524–25

(Abb. 163–66 and 300; Schefold suggests some of these images are not of Aratus but of actual astronomers like Eudoxus, but in every case the visual context suggests a poet, which can only be Aratus).

52. Dissection scene: See Hillert 1990: 232–34; Ferrua 1991: 121–23 (on date and context: 157–59); and Grmek & Gourevitch 1998: 193–96, who identify in extant scholarship no fewer than ten completely different interpretations of the scene, with most taking it as religio-symbolic and thus absent of any scientific meaning. Since no medical instruments are shown (not even a scalpel) and there are (by one count) twelve disciples in attendance, a religious or symbolic meaning seems more likely than a medical or scientific one. The image also falls outside our period of interest (at least probably—experts date it no earlier than 320 A.D., though it could be earlier).

53. Apart from the more fundamental problem of establishing the accuracy and authenticity of extant textual traditions, but since it is beyond the scope of this study to test the conclusions of modern textual critics, modern critical editions of ancient texts shall be trusted.

54. Count determined from a close analysis of comprehensive search results derived from the *Thesaurus Linguae Graecae* (www.tlg.uci.edu). The results of a corresponding analysis from several Latin text databases were similar for the word *physicus* with the same connotation, including the complete *Brepols Library of Latin Texts* (www.brepolis.net) and the *Patrologia Latina*, *Bibliotheca Iuris Antiqui*, and Packard Humanities Institute Demonstration Disks.

Chapter Two

Section 2. The Natural Philosopher as Ancient Scientist

Section 2.1 Defining the Natural Philosopher

55. Besides being obvious, the derivation of *physikos* from *physis* is directly asserted by the 2nd century A.D. grammarian Aelius Herodianus (or a Roman author assuming his name), in frg. 222 of *On the Modification of Words* (*Peri Pathôn*, suppl.). Also: *OCD* 1001 (s.v. "nature").

56. Plato, *Laws* 10.888e-892c, who also links this distinction to a related dichotomy between *physis* and *nomos*, that which is true "by nature" and that which is true "by convention." In *Sophist* 265c, Plato says everything comes into being "either as the product of God's workmanship," whether directly or indirectly, "or else nature produces things from some innate cause without intelligent purpose," which he says is what "many claim and believe." Plato sides with the former, declaring in *Sophist* 265e that all *physis* is "made" by divine *technê*. This is also the gist of Galen's division of causes in On the Natural Faculties 1.1 (= Kühn 2.1–2) into psychê and *physis* (soul and nature), the *psychê* in this case meaning intelligent, deliberative causes (including divine, human, and animal intelligence), which corresponds to what Plato means by *technê*, although Galen, just like Plato, also understood *physis* as a *technê*-like cause in the special and limited sense that it was rationally designed by God (*On the Natural Faculties* 1.12 = Kühn 2.26–30; and see 1.6 and 3.13 = Kühn 2.15 and 2.199), and he was not alone (see von Staden 1996: 95–96). On similar distinctions in Aristotle and other authors, see Schiller 1978–1979, von Staden 1997b: 187–92, Heinemann 2005b, and Cuomo 2007: 7–40. Not all ancient scientists believed in divine design, however (such as the Epicureans or Strato the Aristotelian); nor materialism (*OCD* 910, s.v. "materiality").

57. Heinemann 2000; Leisegang 1941; cf. Aristotle, *Meteorology* 338a20–339a9, *On the Heavens* 268a1–7; etc. (see section 2.2 below). For overall context: *OCD* 1145–46 (s.v. "physics"). For an example of a Roman-period survey of the divisions of philosophy: Seneca, *Moral Epistles* 89. For a detailed modern discussion see Hadot 1979 and (more briefly) Kidd 1988: 349–55. On the origin and evolution of the meaning of the word *physis* see: Naddaf 1992 and 2005; Patzer 1993; R.M. Grant 1952: 3–40; Burnet 1930; and Hardy 1884. See also "The Invention of Nature" in Lloyd 1991: 417–34; also Heinemann 2001, though this is currently incomplete without his promised second and

third volumes. Aristotle produces the clearest ancient definition of *physis* in *Physics* 193a-194a and *Metaphysics* 1014b-1015a, fully analyzed in Buchheim 2001 and Heinemann 2005a. On the Latin equivalent (*natura*) see pertinent studies in Lévy 1996.

58. *LSL* 1373 (s.v. "*physica*" and "*physicus*"); *LSG* 1964 (s.v. "*physikos*") and 1964–65 (s.v. "*physis*"); *OLD* 1376 (s.v. "*physicê*," "*physicus*$_1$," and "*physicus*$_2$"). The equivalent word *physiologia* and cognates (both Latin and Greek) carried the same meaning ("*physio-*," natural, "*-logia*," reasoning, discussion, theorizing) but in the Roman period was less common, and was occasionally employed in the more specific sense of "physiology."

59. So the phrase *physikos anêr* and the solitary word *physikos* (when applied to persons), always means the same thing as the phrase *physikos philosophos*. For *physikos philosophos*, by analogy to *êthikos philosophos*, "moral philosopher," see: Sextus Empiricus, *Against the Professors* 7.7, 10.255, 10.351 (late 2nd century A.D.); Plutarch, *Themistocles* 2.4 (late 1st century A.D.); Eusebius, *Preparation for the Gospel* 14.4.8, 14.13.9, 14.16.11 (early 4th century A.D.); etc. For *physikos anêr* see: Galen, On the Combinations and Effects of Individual Drugs Kühn 11.460–61; and Eusebius, Preparation for the Gospel 10.14.14.

60. For *physikeuomai* see Galen (quoting Julianus), *Against What Julianus Said about the Aphorisms of Hippocrates* Kühn 18a.255–56.

61. Contrary to common assumption, the word "scientist" was not coined until the 19th century (Ross 1964). Thus, "scientists" in a strictly literal sense did not exist even in the days of Galileo or Newton or Harvey or Lavoisier.

62. Evolution of the word physician: On this entire process see Schipperges 1970 and 1976.

Section 2.2 Aristotle's Idea of a Scientist

63. Opening definition quoted from: Aristotle, *Metaphysics* 6.1.1026a.

64. On mathematical objects: Aristotle, *Physics* 193b and *Metaphysics* 1026a, 1059b, 1064a, etc. On what the mathematician does: Aristotle, *Physics* 193b-194a, *On the Soul* 403b14–16, *Metaphysics* 1059b. Analogously, just as mathematical objects only exist when manifested in a material, Aristotle also regarded the soul as the form and function of the body, and hence the soul exists only when the body is alive, cf. Aristotle, *On the Soul* 2.1. For discussion of these and similar passages see Distelzweig 2013, H. Lang 2005, and Modrak 1989.

65. Aristotle, *Metaphysics* 6.1.1026a.

66. On Aristotle's disapproval of their view, see Alexander of Aphrodisias, Commentary on Aristotle's 'Metaphysics' 70 and 72 (early 3rd century A.D.).

67. Aristotle, *Metaphysics* 1005a-b.

68. Aristotle, *Metaphysics* 1005a-b.

69. Aristotle, *Metaphysics* 1037a.

70. Aristotle, *On the Soul* 403a30–403b9.

71. Aristotle, *Metaphysics* 1059b and *On the Soul* 403b14.

72. Aristotle, *Metaphysics* 1064a.

73. Aristotle, *Metaphysics* 1026a, with *On the Soul* 403a28–29.

74. Aristotle, *Physics* 184b17. Parmenides wrote a poem entitled *On Nature* in the 5th century B.C. arguing like a *physicus*, treating the same material, but attacking physical doctrines as absurd. Hence Aristotle argued, "just as the geometer no longer has anything to say to one who denies his first principles—for that belongs either to some

other science or to a science common to all—so, too, for the natural philosopher," and therefore a *physikos* has nothing to say to men like Parmenides (*Physics* 185a).

75. Plutarch, *Themistocles* 2.3 (late 1st to early 2nd century A.D.); Eusebius, Preparation for the Gospel 14.3.6, 14.16.13.

76. Sextus Empiricus, *Against the Natural Philosophers* 2.45–46 (see Appendix C on the title and numeration of the extant books of Sextus Empiricus).

77. For mathematics: *Metaphysics* 1026a; for physics: *Physics* 193b. In practice, Aristotle certainly treated astronomy as part of his program to develop a completed "knowledge of nature" (*Physics* 184a-b; *Meteorology* 338a-339a; *On the Heavens* 268a).

78. On the Latin term *mathematicus* and its Greek equivalent see discussion in chapter 1.2.III.

79. Aristotle, *Physics* 193b.

80. Aristotle, *Physics* 194a; see also *On the Soul* 403b15–19.

81. Aristotle, *Physics* 194a-b; *On the Soul* 403b5–19. In *Posterior Analytics* 1.13–14 (78b30–79a30), Aristotle distinguishes pure mathematics from pure physics and then describes, in effect, a middle science of mathematical physics to mediate between them, adding that even medicine encounters mathematical problems (giving the example of using geometry to solve the problem of why circular wounds take longer to heal than gashes; a proof later accomplished by Herophilus: von Staden 1996: 90). He implies the same for mechanics, optics, harmonics, and astronomy (ibid. 1.9–10, esp. 76a23–76b12). See also Ps.-Aristotle, *Mechanics* 1.847a, on how 'mechanics' results where mathematics and natural philosophy meet. For more on the role of mathematics in Aristotle's natural philosophy see Hussey 2002 and Taub 2003: 106–15.

82. Aristotle, *On Sense and Sensibles* 436a17–436b2.

83. Aristotle, *On Respiration* 480b21–30. My translation of this and the previous passage is more literal than provided by Lennox 2005: 66–68, though his discussion of them supplements mine.

84. Owens 1991 provides a full and detailed examination of this division of pure and applied science in Aristotle. Galen reiterates it, as we shall see in section 2.7, but he describes the principle more generally in *To Thrasybulus* 30 (= Kühn 5.861).

Section 2.3 On Stone & Papyrus

85. As determined from a search of the *Packard Humanities Institute Demonstration Disks*, the *Database of Roman Inscriptions* (containing the volume of the *Corpus Inscriptionum Latinorum* for the city of Rome), and the indexes of numerous epigraphic collections in print.

86. Burstein 1984; and *I.Velia* 21, cf. *Apollo* [Musei provinciali del Salernitano] 2 (1962):125–36.

87. Diogenes of Oenoanda, *Epicurean Inscription*, frg. 114 (col. 1, line 6) = M.F. Smith 1996: 174 (for context and references see *OCD* 457, "Diogenes (5)"). 88. For rendering the word "profession" here I follow *LSG* 660 (s.v. "*epistêmê*" §I.2), as in a trained skill that was regularly practiced, whether for gain (monetary or otherwise) or not.

89. *Fouilles de Delphes* 3.4.2: § 83 & 110, both fragmentary but among lists of names of individuals to whom (and to whose children) the Delphians granted "citizenship" and various other honors (such as the right to consult the oracle first, the right to have cases heard at court first, a release from civic duties, and so on). It is probable Aristokleides and Perses received the same or similar honors—for what reason is unknown, although two doctors (Dio the *iatros* and Metrophanes "of the medical profession," *iatrikên epistêmên*) are also among the honorees (ibid. §87 and 108).

90. For example: *Die Inschriften von Klaudiu Polis* (= *Inschriften griechischer Städte aus Kleinasien* Bd. 31) §160 (*physiko patri*, "biological father"); *P.Mil.Vohl.* 2.73:8 (*physika tekna*, "birthchild"); *IAph* 2007 §12.1109 (*physikôn teknôn*, "children by birth"); *P. Oxy.* 44.3136:20 (*physikê th[u]gatêr,* "daughter by birth"), 44.3183:24 (*huioi physikoi*, "sons by birth"); *P.Lips*. 28:18 (*huion gnêsion kai physikon*, "legitimate son by birth"). A search of the *Duke Databank of Papyri* and the indexes of various papyrological collections produced no clear uses of *physicus* or *physikos* in any other sense.

91. *CIL* 10.388 (= *IRN* 236 = *CIL* 1.1256 and 1_2.1684 = *IG* 14.666 = *ILLRP* 799). The inscription was erected by Menekrates to his deceased wife, "Maxsuma Sadria."

92. This would explain why his distinctively Greek name "by birth" (*phusei*) is different from his Latin name. The expected abbreviation for a freeborn Roman, *Q. f.* ("son of Quintus") does not appear, but only a lone *Q* in the Latin. All the interpreters (see note above) take this as *Quinti*, i.e. "of Quintus" and therefore either "son of Quintus" by adoption or "freedman of Quintus" (the interpreters do not agree on which).

93. There are numerous doctors in the epigraphic record named Menecrates, suggesting a possible medical dynasty (e.g. see Korpela 1987: 167–68 and Rawson 1985: 85).

94. On Asclepiades launching the "winegiving" practice in Italy: Galen, *To Thrasybulus* 24 (= Kühn 5.846); cf. also *IG* 14.666 and *Anonymi Londinensis* 24.30 (cf. W.H.S. Jones 1947). Modern scholarship: Jouanna 1996, Garzya 1999, Touwaide 2000, and observations and sources in B.T. Lee 2005: 179; Rawson 1985: 174–75; and sources and discussion in chapter 3.2.

95. Rawson 1985: 85 argues Menekrates was thus boasting he was a student of the medical sect of Asclepiades, but either way, as Rawson correctly notes, "such careful claims concerning origin and training cannot be paralleled in this period epigraphically, for any other profession."

Section 2.4 'Natural Philosophers' as the Presocratics

96. For instance: Cicero, *Timaeus* 1.2, *Prior Academics* (= *Lucullus*) 2.17.55 (1st century B.C.); Sextus Empiricus, *Against the Professors* 7.89, 7.141; Diogenes Laertius, Lives and Opinions of Eminent Philosophers 10.134; Hippolytus, Refutation *of All Heresies* 1.pinax (early 3rd century A.D.); Eusebius, *Preparation for the Gospel* 14.2.1, 14.3.6.

97. Sextus Empiricus, *Against the Professors* 7.20.

98. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 2.16. Hippolytus also says natural philosophy extended from Thales to Archelaus in *Refutation of All Heresies* 1.10.

99. Sextus Empiricus, *Against the Professors* 7.7.

100. So: Eusebius, *Preparation for the Gospel* 14.2.1.

101. For instance: Tertullian, *Apology* 46 (early 3rd century A.D.); Clement of Alexandria, *Stromata* 2.4.14.2 (late 2nd century A.D.); Sextus Empiricus, *Against the Professors* 7.89; Eusebius, *Preparation for the Gospel* 10.14.10, 10.14.16; Ps.-Plutarch, *Tenets of the Philosophers* [*Moralia*] 883e (composed sometime between the 2nd and 4th centuries A.D.).

102. As 'first' (with the phrase *prôtoi physikoi*): Eusebius, *Preparation for the Gospel* 14.14.7. Similarly: Cleomedes, *On the Heavens* 18, 74, 201 (on dating Cleomedes see note in chapter 3.3, but probably 1st century B.C. to 2nd century A.D.). As 'old' (with various phrasing): *veteres physici*: Cicero, *Prior Academics* (= *Lucullus*) 2.5.13, cf. 2.27.87; *archaioi physikoi*: Posidonius in the early 1st century B.C. (via Strabo, *Geography* 17.1.5, completed early in the 1st century A.D.); Alexander, *Commentary on Aristotle's 'Metaphysics'* 178; palaioi physikoi: Diodorus Siculus, Historical Library 18.1.1 (late 1st century B.C.); presbyteroi physikoi: Eusebius, *Preparation for the Gospel* 14.13.9.

103. Eusebius, *Preparation for the Gospel* 14.4.8, 14.4.12.

104. Referring to the Presocratics: Plutarch, *Themistocles* 2.4; Eusebius, *Preparation for the Gospel* 14.2.1; Diogenes Laertius, Lives and Opinions of Eminent Philosophers 10.90. But including later philosophers: Eusebius, *Preparation for the Gospel* 14.13.9.

Section 2.5 The Roman Conception of the Scientist

105. Galen, *Commentary on Hippocrates' 'On the Nature of Man'* Kühn 15.2.

106. Aulus Gellius, *Attic Nights* 1.9.6–8 (quoted and discussed in chapter 1.2.III); Varro, *On the Latin Language* 10.55.4; Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 1.17.

107. Sextus Empiricus, *Against the Professors* 1.300.

108. Sextus Empiricus, *Against the Professors* 9 and 10 = *Against the Natural Philosophers* 1 and 2 (see chapter 4.8 and Appendix C).

109. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 6.101.

110. Cicero, *On Divination* 2.33 (1st century B.C.). See Carrier 2005a for the contemporary meaning of 'metaphysical naturalism' and a modern example of a naturalist worldview.

111. Tacitus, *Annals* 6.22: *non e vagis stellis, verum apud principia et nexus naturalium causarum*. Such avoidance of common expressions through periphrasis is typical of Tacitean style.

112. Alexander, *Commentary on Aristotle's 'Metaphysics'* 72, 76, 264–265.

113. Cicero, *On the Orator* 1.49.217.

114. Cicero, *On the Nature of the Gods* 1.83.

115. Galen, *On the Uses of the Parts* 11.18 (= Kühn 3.922 = M.T. May 1968: 541); and Galen, *On the Uses of the Parts* 12.14 (= Kühn 4.56 = M.T. May 1968: 577).

116. Galen, *On the Uses of the Parts* 15.1 (= M.T. May 1968: 658).

117. Galen, *On Mixtures* Kühn 1.624 (emphasis added).

118. Galen, *On the Combinations and Effects of Individual Drugs* Kühn 11.460.

119. Plutarch, *Questions at a Party* 8.3.1 (= *Moralia* 720e).

120. Cicero, *On the Orator* 1.49.212. That natural philosophy included elements of what we now call theology will be shown below.

121. See also Aspasius, *Commentary on the 'Nichomachean Ethics'* 35 (early 2nd century A.D.).

122. Philo of Alexandria, *On the Special Laws* 3.117.

123. Galen, *On the Combinations and Effects of Individual Drugs* Kühn 11.426 (also 11.401 and 11.427).

124. Pliny the Elder, *Natural History* 1.21c.9, 1.23c.7, 1.24c.8, 1.25c.9, 1.26c.9, 22.35.1 (1st century A.D.); similarly, Apuleius, *Defense* 45.14 (2nd century A.D.), regarding the medical effects of minerals. Phanias (of Eresus, sometimes sp. Phaenias or Phainias: *EANS* 641) was a colleague of Theophrastus, second head of Aristotle's school during the late 4th century B.C., and wrote on numerous subjects, including history and logic—but most pertinently in this case, he conducted and published research in botany (though none of his works survive). Over sixty fragmentary references to or from this Phanias can be found in the *Thesaurus Linguae Graecae* (as Phanias or Phainias), e.g.

Athenaeus, *The Dinnersages* cites two works by Phanias, *On Plants* (*Peri Phytôn*) at 2.44, 2.59, 2.83, etc., and *Botanical Studies* (*Ta Phytika*) at 2.52, which are probably the works Pliny consulted.

125. Galen, *To Thrasybulus* 28, 29, 30 (= Kühn 5.857, 859, 861). Galen similarly links astronomers and natural philosophers in *On Critical Days* Kühn 9.937.

126. Cicero, *On the Nature of the Gods* 2.34 (Cicero was a good friend and avid pupil of Posidonius: cf. Kidd 1999: 38–40 and 1988: 23–27). We might have actually recovered one of these machines (see discussion in chapter 3.3).

127. Plutarch, *On the Face that Appears in the Orb of the Moon* 26 (= *Moralia* 942b).

128. Alcinous, *Epitome of Platonic Doctrine* (= *Didaskalikos*) 3.4 and 7.1. See commentary in Dillon 1993: 57–60 and 86–89. This treatise also shows Aristotelian and Stoic influences. A previous attribution of it to Albinus has been rejected by recent scholarship, but a date in the 2nd century A.D. is still accepted. For a complete translation and commentary see Dillon 1993. See also *OCD* 53 (s.v. "*Alcinous (2)*"). Note that the division of theoretical philosophy into theology, physics, and mathematics is already in Aristotle (see section 2.2 above).

129. Alcinous, *Epitome of Platonic Doctrine* (= *Didaskalikos*) 7.2–4.

130. Quoted in Eusebius, *Preparation for the Gospel* 11.2.1 (cf. 11.2.5); Aristocles, an Aristotelian philosopher of the 1st or 2nd century A.D., said essentially the same thing about the Platonist view (Eusebius, ibid. 11.3).

131. According to Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 7.134.

132. Eusebius, *Preparation for the Gospel* 11.1.1 (compare with 11.2.1 and 11.7.1).

133. Sextus Empiricus, *Against the Professors* 9.12.

134. Lucian, *Icaromenippus* 21.

135. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 5.58 (something similar is said of Strato in Seneca, *Natural Questions* 6.13.2). Strato of Lampsacus (of the early 3rd century B.C., discussed in chapter three), third head of Aristotle's school, was frequently paired with this epithet in ancient literature: e.g., Cicero, *On the Nature of the Gods* 1.35; Tertullian, *On the Soul* 15; Strabo, *Geography* 1.3.4; Galen, *On Semen* Kühn 4.629 and *On Trembling, Palpitation, Convulsion, and Shivering* Kühn 7.616; Plutarch, *On the Cleverness of Animals* 3 (= *Moralia* 961a) and *On Tranquility of Mind* 13 (= Moralia 472e); Sextus Empiricus, *Against the Professors* 7.350, 8.13, 10.155, 10.177, 10.228, 10.229 and *Outlines of Pyrhhonism* 3.32; Porphyry, *On Abstinence* 3.21.8 (late 3rd century A.D.); etc.

136. Marcus Aurelius, *Meditations* 7.67.1. This and many other sentiments of Aurelius on this subject are discussed in chapter 4.2.

137. Alexander of Aphrodisias, *Commentary on Aristotle's 'Metaphysics'* 646.

138. Eusebius, *Preparation for the Gospel* 14.9.4 (also implied by Tertullian, *To the Nations* 2.2).

139. Quintilian, *Minor Declamations* 283.4.3 (see also: 268.4 and 268.9). This work might be the unauthorized publication of class material from Quintilian's lectures by some of his students (cf. Quintilian, *Education in Oratory* 1.pr.7 and 7.2.24), or possibly not even his, though it would still date from his era (cf. *OCD* 421, s.v. "Declamationes pseudo-Quintilianeae").

140. This "case" comes from the 1st century A.D. The earliest extant references in Latin to the *physici* as a class appear in the 2nd century B.C. in works that introduced Greek genres or material into Latin: Lucilius, *Satires*, frg. 26.635.64, says "all the *physici* say that from the very beginning man draws his existence from a soul and a body," and a *physicus* was a character in the lost play *Chryses* by Pacuvius, as reported in Cicero, *On Divination* 1.131.

Section 2.6 The Methods of Roman Scientists

141. Sextus Empiricus, *Against the Professors* 7.89; see also ibid. 7.126 and *Outlines* of Pyrrhonism 1.178.

142. Lactantius, *Divine Institutes* 3.6.

143. Sextus Empiricus, *Against the Professors* 7.127.

144. Cicero, *On the Nature of the Gods* 1.83.

145. Cicero, *On Divination* 1.109, 1.111.

146. Varro, *On the Latin Language* 10.55.4.

147. Vettius Valens, *Anthologies* 248.

148. Cicero, *On Divination* 2.29–33.

149. Plutarch, *Questions at a Party* 8.3.1 (= *Moralia* 720e); armchair methodology (albeit based on real observations in hunting, fishing, and agriculture) also pervades Plutarch, *Natural Questions* (= *Moralia* 911c-919). As another example of unscientific behavior, in his *Life of Apollonius of Tyana* 2.30, Flavius Philostratus claims the *physici* could deduce a person's character from an inspection of the features of their eyes and face (similar to the 19th century fad of reading the bumps on someone's head). However, this is the only reference in our period to *physici* as a class embracing the pseudoscience of physiognomy (on which, see Barton 1994a: 95–132), and it appears only in the context of a depiction of Indian high society that is pure fantasy.

150. Galen, *On the Combinations and Effects of Individual Drugs* Kühn 11.547.

151. Per discussion and sources in chapter one.

152. Cicero, *On the Boundaries of Good and Evil* 1.20. In this case, Cicero has in mind the mathematical understanding of infinite divisibility (possibly deriving in part from the work of Archytas in the early 4th century B.C.) which led to the method of exhaustion (a precursor to calculus, employed by the time of Archimedes in the 3rd century B.C.). This partly resolved the paradoxical analyses of Parmenides and Zeno, which the atomism of Epicurus had resolved in a different way by declaring the infinite division of matter to be impossible. See Johansen 1998: 54–58, 65–74, 432–44, and Hussey 2002: 221–25.

153. See Mueller 1982: 92–95 and 2004: 62–63, Verde 2013, and *OCD* 1174 (s.v. "Polyaenus (1)"). Epicurus nevertheless used geometry in his natural philosophy (cf. Taub 2003: 133), and like the Skeptics who rejected even physics yet nevertheless studied the hell out of it just to debunk it, several Epicureans became obsessed with mathematical study. Hermarchus, like Polyaenus a pupil of Epicurus himself, wrote an entire treatise *On Mathematics* (Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 10.24–25). In the late 3rd century and early 2nd centuries B.C. the Epicurean philosophers Philonides and Eudemus of Pergamum were practicing mathematicians who shared advanced mathematical treatises with Apollonius of Perga (on whom see chapter 3.3), and fragments of a biography of Philonides recovered from Herculaneum reports that he corresponded with several other mathematicians (see: Crönert 1900; *DSB* 1.179, in s.v. "Apollonius of Perga"; *OCD* 122–23, in s.v. "Apollonius (2)"; *EANS* 659 and *OCD* 1135, s.v. "Philonides (2)"). In the early 1st century B.C. the Epicurean philosopher Zeno of Sidon composed sophisticated Epicurean criticisms of mathematics, which came near to anticipating non-Euclidean geometry and modern theories of induction (*EANS* 847; *DSB* 14.612–13; *OCD* 1588, s.v. "Zeno (5)"). Mueller also links the Epicureans Basilides (*EANS* 190), Protarchus (*EANS* 702), and Demetrius (EANS 233) with serious work in mathematics (on the latter, including fragments of his mathematical work recovered from Herculaneum, see De Falco 1923). See, however, Netz 2015 (who argues Epicureans only wrote against mathematics, and the few men identified as Epicurean mathematicians might not have been Epicureans).

154. Cicero, *On the Boundaries of Good and Evil* 1.63.

155. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 10.31.

156. Cicero, *On the Boundaries of Good and Evil* 3.1.4. A similar complaint appears to underlie remarks in Ptolemy, *On the Criterion* 4–6; as well as Galen, *On the Difference among Pulses* Kühn 8.588, *On the Natural Faculties* 1.1 (= Kühn 2.1–2), and *On the Therapeutic Method* 1.5.5–7. See related commentary in Hankinson 1991a: 132–33.

157. For example: Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 7.83. The Platonists certainly agreed (e.g. Alcinous, *Epitome of Platonic Doctrine* 4–7), and we have already seen the Aristotelians did. The Stoics had advanced formal logic well beyond Aristotle, cf. e.g. Galen, *Education in Logic* and Russo 2003: 218–21.

158. Galen, *Commentary on Hippocrates' Sixth Book on Epidemics* Kühn 17b.306 and *On Examinations by which the Best Physicians Are Recognized* 8.4.

159. Cicero, *On the Boundaries of Good and Evil* 1.19.

160. Cicero, *On Divination* 2.37 (cf. Aristotle, *Physics* 187a28).

161. Cicero, *On Fate* 25.1 and 18.14.

162. Cicero, *On Divination* 2.33.

163. Alexander of Aphrodisias, *Commentary on Aristotle's 'Metaphysics'* 652 and 719.

164. Plutarch, *On Why You Should Not Borrow Money* 5 (= *Moralia* 829c).

165. Galen, *On the Uses of the Parts* 6.12 (= M.T. May 1968: 308).

166. See Aristotle, *Physics* 194b-195a and 198a-b, *Metaphysics* 983a-b. The material cause refers to the material something is made of and how that affects what happens; the formal cause is the shape or structure into which that material is formed and how *that* effects what happens; while the efficient cause is what we today more commonly mean by a cause—an event preceding the effect without which the effect would not occur; Meanwhile the instrumental cause is the particular instrument or means by which en effect is brought about (e.g. an efficient cause of an object's motion may be a blow; the instrumental cause would be which specific tool or object delivered the blow); and a final cause is the end goal or reason for something is brought about (e.g. the motivation of an agent; the reason they brought about the effects they did; in modern evolution science, and in ancient natural selection theory, it would include adaptive functions, not just the intentional goals of agents).

167. Sextus Empiricus, *Against the Professors* 10.250.

168. Plutarch, *On the Principle of Cold* 8 (= *Moralia* 948c).

169. Philo of Alexandria, *On the Descendants of Cain* 7 (see also *On Abraham* 99). For an example of *physici* speaking allegorically, see Plutarch, *Lovetalk 24* (= *Moralia* 770a) and Servius, *On Virgil's 'Aeneid'* 1.47.1. See *OCD* 1115 (s.v. "personification").

170. Heliodorus, *Aethiopica* 9.9.5 (see also Strabo, *Geography* 1.2.8). For some discussion and sources on this philosophical use of allegory see J. Stern 2003: esp. 52–53, 57–62, 67. And for a summary and bibliography on the practice and its popularity see Carrier 2014a: 114–24.

171. Eusebius, *Preparation for the Gospel* 1.8.13.

172. Eusebius, *Preparation for the Gospel* 14.14.7.

173. Eusebius, *Preparation for the Gospel* 14.16.11.

174. Eusebius, *Preparation for the Gospel* 14.16.13.

175. That Galen argued the evidence from human anatomy clearly supported the theory of intelligent design: See chapter 3.8.IV.

176. Vitruvius, *On Architecture* 8.pr.4.

177. Diodorus Siculus, *Historical Library* 15.48.4 (see also 16.61–64).

178. Diodorus Siculus, *Historical Library* 15.50.3. See discussion in chapter 3.3.

179. Alexander of Aphrodisias, *Problems and Solutions in Scholastic Physics* 98. Taub 2003: 125–68 provides a detailed examination of how natural philosophers replaced divine with natural causation in meteorology. And see related discussion in chapter 3.7.III.

180. Plutarch, *On Superstition* 6 (= *Moralia* 167e). Seneca argued the same point in his own treatise *On Superstition*, which is lost but quoted in Augustine, *City of God* 6.10. It appears that disdain for natural philosophy was more evident in early Athens and declined substantially after that (see note in chapter 1.3), though even in the Roman era scientific activities could sometimes be perceived and attacked by an ignorant public as malevolent magic (cf. Apuleius, *Apology* 16.7, 29, 38, etc., with commentary in S.J. Harrison 2000) or as dangerously impious (see the example concluding chapter 4.5 and discussion in chapter 3.5).

181. Cicero, *On the Nature of the Gods* 1.35 and *Prior Academics* (= *Lucullus*) 2.38.121.

182. Cicero, *On the Nature of the Gods* 1.32 (probably referring to the Antisthenes who was a student of Socrates and wrote between the late 5th and early 4th century B.C.).

183. A detailed survey of the various beliefs of natural philosophers with respect to the nature and existence of God or gods is provided in Sextus Empiricus, *Against the Professors* 9.49–194.

184. See remarks in S.J. Harrison 2000: 64. For more on the suspected atheism of natural philosophers (and pagan discontent with it) see French 1994: 8–10, 17–18. Popular anxieties of this kind are also reflected in the defensive remarks of Lucretius, *On the Nature of Things* 5.110–125 and the fears voiced in Plato, *Laws* 10.886d-e.

185. Vettius Valens, *Anthologies* 250. This does not mean all natural philosophers rejected astrology—many embraced it and attempted to give it a scientific explanation, most notably Ptolemy, as exemplified in his astrological *Tetrabiblos*, and possibly Posidonius two centuries before him. See Carrier 2016 (index, "astrology").

186. Cicero, *On Divination* 2.27 and Strabo, *Geography* 1.2.8. The strategy of keeping quiet is suggested by Heliodorus, *Aethiopica* 9.9.5.

Section 2.7 Mathematics & Causation

187. That the main interest of the *physicus* was to discover the causes of things: As I've argued in the previous section. Lloyd & Sivin 2002: 140–87 survey this and other objectives of the natural philosophers, which included, also, categorizing and cataloguing the universe, and quantifying and modeling it.

188. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 7.132–33.

189. Extended quote of Posidonius: Text from Simplicius, *Commentary on Aristotle's 'Physics'* 2.2.291–92 (commenting on Aristotle, *Physics* 2.2.193b). Though it is not important here, some scholars suggest the "Heraclides of Pontus" is an interpolation and that the text originally said just "someone" (cf. Kidd 1988: 133 and *DSB* 15.204, in s.v. "Heraclides Ponticus").

190. On Geminus' date see references in *OCD* 6207, correcting *DSB* 5.344–47, but corrected in turn by Evans & Berggren 2006: 17–22. See also *EANS* 344.

191. The gist and focus of these commentaries vary considerably, and they are worth comparing against each other. For example: Evans & Berggren 2006: 49–58, 250–55; Bowen & Todd 2004: 193–204; Mueller 2004; Russo 2003: 191–94; Kidd 1988: 129–36; Edwards 1984: 155–57; and (in connection with a related passage in Seneca discussed below): Stückelberger 1965: 55–68.

192. Kidd 1988: 134.

193. Mueller 2004. I say 'gives the impression' since what Mueller means to say on this point is unclear (and he seems rather to agree with me elsewhere), but if this was not his intent, then I am responding to anyone who takes it to be, or who embraces such a conclusion on their own (e.g. M.R. Wright 1995: 159–61).

194. See relevant evidence and discussion in sections 2.2 and 2.5 above.

195. As we saw in section 2.6 above, though more examples will be given in chapter 3.3.

196. Ptolemy, *Analemma* 1 (following Edwards 1984: 79). That natural philosophy benefits from a mathematical method is articulated at length in Ptolemy, *Almagest* 1.1 (see Toomer 1984: 35–37 and discussion in Taub 1993: 19–37). Nevertheless, Ptolemy thought progress could still be made even in non-mathematical natural knowledge, and held nonmathematical sciences in esteem (e.g. he frequently compares "astrology" as one such science, with "medicine" as another successful albeit unmathematized science, in *Tetrabiblos* 1.2–3).

197. We will discuss Ptolemy's work in more detail in chapters 3.3 and 3.4, but illustrating the present point is the fact that he puts his natural philosophy in the first (and possibly last) books of his *Optics*, thus keeping it more or less distinct from his mathematical (and considerably empirical) work in the middle books, and yet these remain thoroughly interdependent. Likewise, he sets up all his essential hypotheses in natural philosophy in the first chapters of the *Almagest* (literally the *Mathematical Treatise*, cf. ibid. 1.4–8), reserving the rest of that book for his mathematical treatment (derived from those initial hypotheses in conjunction with observations), while placing the remainder of his celestial natural philosophy in a completely separate book, the aptly-named *Planetary Hypotheses* (though even there switching between natural philosophy and mathematical argument as the subject requires). On Ptolemy's opinions and arguments in natural philosophy in general see Taub 1993.

198. Points about Hero: See analyses in Tybjerg 2004 and 2005.

199. From Geminus as paraphrased in Proclus, *Commentary on the First Book of Euclid's 'Elements'* pr.1.13.41 (early 5th century A.D.). See Evans & Berggren 2006: 43–48, 243–49 for translation and commentary. Geminus' remarks here come from an extensive division he made in a comprehensive treatise on mathematics, which is now lost but summarized in Proclus, *Commentary on the First Book of Euclid's 'Elements'* pr.1.13.38–42. Geminus first divided mathematics into pure and applied (or in our parlance "mathematics" as such and "mathematical sciences"), and then put astronomy under applied mathematics (along with mechanics, optics, and harmonics, as well as surveying and logistics).

200. Diodorus of Alexandria (of the early 1st century B.C., on whom see chapter 3.3), probably from his (lost) commentary on the *Phenomena* of Aratus, as quoted by Achilles (Tatius?), Introduction to the 'Phenomena' of Aratus 2 (= Maass 1958: 30), which was written in the 3rd or 4th century A.D.

201. Quoted in Theon of Smyrna, *Aspects of Mathematics Useful for Reading Plato* 3.41.199 (cf. 3.39–41.198–200), from the lost work of Dercyllides, *The Spindles with which the 'Republic' of Plato is Concerned* (see EANS 241–42).

202. Theon of Smyrna, *Aspects of Mathematics Useful for Reading Plato* 3.34.188 (cf. 3.32.166), translating: *oude autos mentoi, dia to mê ephôdiasthai apo phusiologias, sunoiden akribôs, tis hê kata phusin kai kata tauta alêthês phora tôn planômenôn kai tis hê kata sumbebêkos kai phainomenê: hupotithetai de kai houtos ton men epikuklon*.... (the passive infinitive *ephôdiasthai* is from the verb *ephodiazô, LSG* 746: "to furnish with supplies for a journey").

203. Hipparchus is said to have credited it as "more probable" in the sentence immediately preceding the above: *hoper kai sunidôn ho Hipparchos epainei tên kat' epikuklon hupothesin hôs ousan heautou, pithanôteron einai legôn pros to tou kosmou meson panta ta ourania isorropôs keisthai kai homoiôs sunarêrota* ("Being aware of this fact, Hipparchus approved the epicyclic hypothesis as his own, saying it was more plausible that all the heavens are laid down evenly balanced against the middle of the cosmos and joined together in the same way.").

204. Kidd 1978: 11. Kidd cites an unrelated passage from Plutarch in defense of his reading of Theon (Plutarch, *On the Face that Appears in the Orb of the Moon* 4 = *Moralia* 921d-e), but this nowhere says Hipparchus was unqualified to discuss physics or that it was inappropriate of him to do so. Cherniss 1957: 45 adds an unjustified interpretive note to that effect. But all the Greek text actually says is that his physics of vision is not generally accepted (*pollois*

ouk areskei physiologôn peri tês opseôs), and that the present discussion is not an occasion to debate it. In particular, the speaker says "it is the task" (*ergon*) of someone who believes in the visual ray theory to address questions based on that theory (like the lengthy question the speaker had just asked before this), but "it is not now" (*ouketi*) our task to investigate the visual ray theory itself (though it would be appropriate on some other occasion), or "it is no longer" our task to debate it (because we and most others already accept it). There is nothing here about the different "provinces" of mathematicians and philosophers as Cherniss and Kidd claim. On 'visual ray' theory (and the alternative embraced by Hipparchus) see chapter 3.5.

205. Hence Kidd also incorrectly reads Posidonius as criticizing Heraclides (as noted above). It is with these and other errors of interpretation that Kidd 'discovers' a non-existent dispute between 'philosophers' and 'scientists', as if these were ever different people (see Kidd 1988: 134–36, especially in contrast with the *actual* text and context of Theon's other citations of Hipparchus, which do not conform to Kidd's reconstruction).

206. For example, on Ptolemy's embrace of this principle (that hypotheses in astronomy derive from natural philosophy) see Taub 1993: 39–45.

207. Seneca, *Moral Epistles* 88.24–28. For extended commentary see Kidd 1988: 359–65 and Stückelberger 1965: 55–68. The context is an extended argument that philosophy is more important than the 'liberal arts', which included mathematics and astronomy (see chapter 4.6.I and chapter five of Carrier 2016).

208. Strabo, *Geography* 2.5.2–4.

209. Ptolemaïs, *Pythagorean Elements of Music*, frg. 1, quoted in Porphyry, *Commentary on Ptolemy's Harmonics* 22.22–23.22. For sources on Ptolemaïs see Carrier 2016 (index). The word translated as 'harmonic scientists' is *kanonikos*, those who study the 'canon' of harmonics. On the monochord as an ancient scientific instrument: Creese 2010.

210. J. Mansfeld 1998: 94–95. Cuomo 2000: 81–88 implies a similar conclusion for Pappus, but is rightly challenged by Mueller 2000 (though in fairness even Cuomo concedes there was overlap between the categories of philosopher and mathematician).

211. On Hero as philosopher see Tybjerg 2003, 2004, 2005; Cuomo 2002; and Fake 2014. In *Siegecraft* 1, Hero says tranquility is achieved not "by the investigation of arguments" (*dia tôn logôn tên...zêtêsin*) but "by a philosophy of machines" (*dia tôn organôn philosophiâ*). Galen's comparable assault against Chrysippus on the anatomical location of the soul is in Galen, *On the Doctrines of Hippocrates and Plato* (for relevant analysis see Tieleman 1996). This is the same Galen who wrote *That the Best Doctor is also a Philosopher*, whose thesis is self-explanatory.

212. For example, Vitruvius, *On Architecture* 1.1.1–2, 1.1.7, and 1.1.11, with 6.pr.6–7. See related discussions in chapters five and seven of Carrier 2016.

213. Feke 2014 (with Feke 2011).

214. In J. Mansfeld 1998: 104 n. 355 he presents evidence against himself, noting that, e.g., Plutarch can say much the same thing as Hero and Pappus do "without implying that he prefers not to be called a philosopher himself."

215. Pappus, *Mathematical Collection* 5.19.350.

216. Pappus, *Mathematical Collection* 8.1.1022–24.

217. The use of the phrase *kai pasi tois apo tôn mathêmatôn* here is essentially identical to that in Diogenes Laertius, and carries the same connotations when following (again) the lone plural of *philosophos* (see note above).

218. The word used for the "practical" part of mechanics is *cheirourgikon*, literally "hands-on work" or "work done by hand." The word used for the "theoretical" part is *logikon*, which is said to consist not only of physics but also the mathematical study of *geômetria*, *arithmêtikê*, and *astronomia* (and we can assume Hero would also have included harmonics: see discussion of the 'quadrivium' in chapter five, and discussion of engineering education in chapter seven, of Carrier 2016).

219. This textual note is Alexander's, which means there were two textual variants known to him: the phrase *to de dioper ou phusikos* ended either with *ho logos* or *ho tropos*. Alexander sided with *ho logos*, which we find in the received text of Aristotle. The difference does not matter here.

220. Alexander of Aphrodisias, *Commentary on Aristotle's 'Metaphysics'* 169.

221. Cicero, *On Divination* 2.43.

222. Cicero, *On the Boundaries of Good and Evil* 2.5.15.

223. Cicero, *On Divination* 2.34. On the ancient discovery of lunisolar tide theory see discussion and notes in chapter 3.3.

224. Cicero, *On Divination* 2.33–34. It is perhaps worth asking if these claims are even true. The last three claims appear to be fact: the phenomenon of 'sympathetic vibration' is well-documented (Rossing & Fletcher 1995); shellfish do grow and shrink with lunar phase as a result of their circalunal rhythm (Cloudsley-Thompson 1980); and though there are elements of superstition in timbering (Meiggs 1982: 331–32), according to some woodcutting experts (e.g. "Primavera" 1994) tree sap tends to be "down" or "low" in conjunction with the drop in temperature and light conditions (both solar and lunar), hence sap is at its lowest on a winter night during a new moon, and since less sap means less food to attract and feed bugs, cutting at the low increases timber quality by reducing discoloration or degradation from insect infestation (Theophrastus was aware of the reason: *Inquiry on Plants* 5.1.1–4; cf. Pliny the Elder, *Natural History* 16.74.188–92; Vitruvius, *On Architecture* 2.9.2–4; Cato, *On Agriculture* 37.3–4). However, what actually 'drops' in these conditions is still debated, whether it is the actual water weight, or flow pressure, or sugar content of the sap (Edlin 1976: 239–45; Thomas 2000: 48, 57). In contrast, however, the first two claims are dubious: the livers of many animals might grow as they store fat for winter, but I could find no evidence that any species of mouse was more prone to this than any other wintering mammal; and Cicero's description of a plant that starts flowering in winter, and later sheds bursting seed pods, could fit several plants of the region, but not the dry pennyroyal (i.e. fleabane, which is what his phrase *puleium aridum* usually denotes), and even if this denotes a different plant, "on the very day of the Solstice" is certainly hyperbole.

225. Cicero, *On Divination* 1.110–13, 1.126–27. These findings were also used as a 'proof of concept' in support of developing astrology as a science (and likewise other arts of divination).

226. On this point about physiology in general: Cicero, *On Divination* 2.37.

227. Galen, *On Semen* Kühn 4.580 (and 4.569).

228. Alexander of Aphrodisias, *Commentary on Aristotle's 'On Sensation'* 6; and see Alexander of Aphrodisias, *Problems* 1.99.

229. Galen, *On the Natural Faculties* 2.9 (= Kühn 2.126). Though this implies the Erasistrateans separated themselves as doctors from natural philosophers, Galen's representation of his opponents' views is (as here) polemical and frequently dubious. As Erasistratus was famously involved in the study of physiology (cf. sources in Appendix B) and Erasistrateans relied extensively on physiological dogmas (two facts even Galen confirms throughout his writings) clearly Galen's depiction of their opinion on the subject is fundamentally inaccurate. 230. Galen, *On Critical Moments* Kühn 9.738–739. Celsus, *On Medicine* pr.47 echoes the same idea, in effect that a *medicus* performs better when he is also a *physicus*.

231. Cicero, *On the Republic* 5.5.14. See also related point in chapter five of Carrier 2016.

232. Galen, *On Conducting Anatomical Investigations* 2.2 (= Kühn 2.286–87, cf. Kühn 283–86 for context). Galen means it is the business of a natural philosopher to demonstrate the intentions of the Creator in designing particular organs, thus a physicus could still be a creationist. But what is important here is that physici are interested in anatomical research and the discovery of organ function, e.g. Galen, *On the Natural Faculties* 3.8 and 3.12 (= Kühn 2.174 and 2.185). On all these points see the elegant summary in Galen, *On the Uses of the Parts 17.1–2 (= M.T. May 1968: 730–33), and see Hankinson 1994b on the diverse uses Galen had for empirical dissection and his advocacy of it as a method, and Hankinson 1988: 142–45 on elements of this passage specifically. Galen also elaborates on the serious need for detailed anatomical knowledge for performing successful surgeries in On Conducting Anatomical Investigations* 1.3, 2.2,

3.1, 3.9, 4.1, 7.13 (= Kühn 2.229, 2.283–84, 2.340–46, 2.393–97, 2.416–20, 2.632–34), and for developing effective treatments (cf. Ormos 1993: 172). This stood in contrast to doctors of the Empiricist or Methodist sects, like Soranus, who claimed dissection was only useful for natural philosophy, though even he conceded this should "nevertheless be studied for the sake of profound learning" (Soranus, *Gynecology* 1.2, 1.5).

233. Philo of Alexandria, *On the Special Laws* 3.117.

234. Alexander of Aphrodisias, *Commentary on the Book 'On Sensation'* 6.27–7.6. See also: Alexander of Aphrodisias, *On Fevers* 25.13; Aristotle, *On Sense and Sensibles* 436a17-b1.

235. Sense perception: Galen, *On Irregular Intemperance* Kühn 7.743; Alexander of Aphrodisias, *Commentary on the Book 'On Sensation'* 92; Sextus Empiricus, Against the Professors 8.13; Vitruvius, *On Architecture* 6.2.3.2; etc.

236. Human gestation and fetal development: *Philo of Alexandria, On the Special Laws 3.117, On the Creation of the World 132, Allegorical Interpretation 2.6, Questions on Exodus 1.frg.7a (knowledge attributed to physici in these passages also concerns such diverse subjects as menses, sexual dimorphism, heart physiology, and the decay of corpses); Sextus Empiricus, Against the Professors 5.59.*

237. Anatomy and physiology of a woman's breasts: Tertullian, *On the Flesh of Christ* 39.

238. Contents and function of blood: Galen, *On the Elements according to Hippocrates* Kühn 1.506.

239. Skeletal anatomy of the human jaw: Galen, *On the Uses of the Parts* 11.8 (= Kühn 3.922 = M.T. May 1968: 516–20).

240. Nature and causes of heat retention during sleep: Galen, *Commentary on the Aphorisms of Hippocrates* Kühn 17.455.

241. Galen, *On the Uses of the Parts* 12.7 (= M.T. May 1968: 560); for example, Cicero cites both *physici* and *medici* as experts on the physiology of human sensory organs (Cicero, *Tusculan Disputations* 1.20.46). For more examples of natural philosophers examining medical questions see Nutton 2013: 145–49.

242. Advancing astronomical theories and making observations of the stars: Diodorus Siculus, *Historical Library* 1.28.2; Philo of Alexandria, *On the Life of Moses* 2.103; Varro, *On the Latin Language* 5.69.2; M. Verrius Flaccus, *On the Meaning of Words*, p. 339, §44 (1st century B.C./A.D., via an epitome of Festus in the late 2nd century A.D.); Alexander of Aphrodisias, *Problems* 2.74; Eusebius, *Preparation for the Gospel* 10.14.10 and 15.p.1.

243. Calculating the size of the earth and the sun: Cleomedes, *On the Heavens* 90, 152.

244. Discovering the moon is lit by the sun: Cleomedes, *On the Heavens* 201.

245. Precession of the equinoxes: *Cicero, On the Boundaries of Good and Evil 2.31.102.*

246. Earth spins on its axis: Alexander of Aphrodisias, *Commentary on Aristotle's Metaphysics* 421.

247. Age and fate of the universe: Sextus Empiricus, *Against the Professors* 8.146, 10.169; Pseudo-Plutarch, *Tenets of the Philosophers* 887a; Cleomedes, *On the Heavens* 6.

248. Geography and climatology: Diodorus Siculus, *Historical Library* 2.37.5, 3.51.1; Cleomedes, *On the Heavens* 22, 60; Lucian, Demonax 22; Pomponius Mela, Description of the Lands 3.45.1 (1st century A.D.); Apuleius, *On the World* 8.2 (2nd century A.D.).

249. Causes of lightning and earthquakes: Seneca the Younger, *Natural Questions* 6.12.1.2 (1st century A.D.); Cicero, *On Divination* 2.30, 2.43.8.

250. Source of the Nile etc.: Strabo, *Geography* 17.1.5; Diodorus Siculus, *Historical Library* 1.38.4; Lactantius, *Divine Institutes* 3.8.

251. Nature of mind and soul: Eusebius, *Preparation for the Gospel* 11.28.9, 13.13.30, 15.20.2; Plutarch, *Against Colotes* 21 (= *Moralia* 1119b); Porphyry, *On Abstinence* 3.21.8 (late 3rd century A.D.).

252. Sense of smell: Alexander of Aphrodisias, *Commentary on the Book 'On Sensation'* 92.

253. Nature of sound: Sextus Empiricus, *Against the Professors* 8.13.

254. Nature of vision: Vitruvius, *On Architecture* 6.2.3.2.

255. Habits and characteristics of animals: Claudius Aelianus, *On the Characteristics of Animals* 16.29 and *Miscellaneous History* 13.35 (late 2nd to early 3rd century A.D.); Plutarch, *Alexander* 44.2; Pliny the Elder, *Natural History* 1.8c.3, 8.21.59.

256. Nature of space and time: Sextus Empiricus, *Against the Professors* 9.331, 10.155, 10.169, 10.177, 10.181; Alexander of Aphrodisias, *Commentary on Aristotle's Metaphysics* 660; Cicero, *On Fate* 24.6.

257. Nature of heat and fire: *Galen, Against Lycus Kühn 18.224, On the Combinations and Effects of Individual Drugs Kühn 11.475 and 11.513.*

258. Nature of motion: Sextus Empiricus, *Against the Professors* 10.42, 10.45; Galen, *On the Combinations and Effects of Individual Drugs* Kühn 11.585; Plutarch, *Agesilaus* 5.3.

259. Seneca, *Natural Questions* 2.1.1–2.2.1 (divisions of natural philosophy match divisions of the universe: 2.1.1 and 2.2.1; astronomy and astrophysics: 2.1.1; meteorology: 2.1.2; geology and botany, etc.: 2.1.2). This division is as old as Aristotle, *Meteorology* 1.1.338a-339a.

260. See: Cicero, *Prior Academics* (= *Lucullus*) 2.36.117; Vitruvius, *On Architecture* 8.pr.1.13, 8.pr.4.7; Galen, *On the Elements according to Hippocrates* Kühn 1.439, On *the Uses of the Parts* 14.7 (= Kühn 4.165 = M.T. May 1968: 632), *Commentary on Hippocrates' 'On the Nature of Man'* Kühn 15.7; Eusebius, *Preparation for the Gospel* 1.pr.1, 1.8.1; Sextus Empiricus, *Against the Professors* 9.365, 10.1, 10.248; Alexander of Aphrodisias, *Commentary on Aristotle's Metaphysics* 180, 202, 224, 262, 602. etc.

261. Vitruvius, *On Architecture* 2.1.9.10.

262. Galen, *On the Uses of the Parts* 14.7 (= Kühn 4.165 = M.T. May 1968: 632).

263. Galen, *On the Combinations and Effects of Individual Drugs* Kühn 11.475.

Section 2.8 Summary & Conclusion

264. Nicarchus's poem is in the *Anthologia Graeca* 11.241.

265. *Lives of Aesop*, vita g § 67 (= e *cod.* 397 *bibliothecae pierponti morgan, recensio* 3), on which see Perry 1936.

266. This was a trope of the time, e.g. Lucian, *Hermotimus* 11–12; Plutarch, *Questions at a Party* (= *Moralia* 612c-748d); and see M. Clarke 1971: 92–93 and S.J. Harrison 2000: 30–31. But it was not a fiction: Plutarch, *Advice about Keeping Well* 20 (= *Moralia* 133; discussing natural philosophy: 133e; discussing mathematics: 133a) and *That Following Epicurus is Unpleasant* 13 (= *Moralia* 1095c-1096c: discussing harmonics and music theory); hence academic societies (Museums) were often dinner clubs (see chapter eight of Carrier 2016). However, such talks were not always over dinner, and they often brought up sound empirical and mathematical science: Galen, *On the Affections and Errors of the Soul* 2.5 (= Kühn 5.80–93; esp. 5.92–93; this is sometimes identified as two books, *Affections* and *Errors*, so 2.5 means Errors 5); Plutarch, *On the Face that Appears in the Orb of the Moon* 1–23 (= *Moralia* 920b-937c).

Chapter Three

Section 3. The Roman Idea of Scientific Progress

267. That any survey of the achievements of ancient scientists is only a survey of what we know about them: See the pointed comments on this problem in Lloyd 1981: 256–60 and Nutton 2013: 1–17.

268. Rather than delve into hundreds of questions and controversies, what follows is simply a summary of established scholarship from standard references (the *EANS*, *DSB*, *NDSB*, and *OCD*; and James & Thorpe 1994) and what is agreed among expert scholars (including Breidbach 2015, Russo 2003, Lloyd 1973, and Sarton 1959, as well as others to be named). For a brief but useful survey of the modern historiography of ancient science see Rihll 2002. Many more scientists are known than I will name (a more complete list is in *EANS*).

Section 3.1 The Growth of Ancient Science

269. See Lloyd 1970: 16–98. Aristotle in turn had built on the work of his numerous and divergent predecessors. For a near-comprehensive list of pre-Aristotelian scientists and natural philosophers, see Appendix B.

270. *DSB* 1.250; everything else that follows summarizes *EANS* 141–45 (with 145–52), *DSB* 1.250–81, *NDSB* 1.99–107, *OCD* 159–63, Lloyd 1970: 99–124, and Shields 2007. For the philosophical function and context of Aristotle's work in biology see French 1994: 6–82 and Lennox 2005. On the method and practice of Aristotle's scientific research see, for example, Boylan 1983 (biology), Taub 2003: 77–115 (meteorology), and Lloyd 1996b (general). For a good discussion of the motives and empirical nature of all of Aristotle's scientific work see Hankinson 1995a and 1995b.

271. Aristotle's systematization of scientific methodology is laid out principally in the combination of the *Posterior Analytics* and the *Topics*, although important digressions add to the subject in the *Physics* and *Metaphysics* (relevantly discussed in Bolton 1991, Lloyd 1992a, and Crombie 1994: 1.229–76). On Hellenistic improvements: Russo 2003: 171–202, Crombie 1994: 131–228, Lloyd 1982, and relevant discussions here in section 3.7. Breidbach 2015 and Lloyd 1979 and 1987 further discuss the origin and expansion of scientific methods and ideals throughout antiquity.

272. See previous notes and *OCD* 232–33, 449 (s.v. "biography, Greek," "*didaskalia*") and Zhmud 2003 and 2006. Aristoxenus wrote numerous biographies (*DSB* 1.281–83 and *OCD* 163–64); Dicaearchus of Messana, various histories and biographies (*OCD* 447, s.v. "Dicaearchus"); Eudemus of Rhodes, histories of the sciences of astronomy, arithmetic, and geometry (*DSB* 4.460–65, s.v. "Eudemus of Rhodes" and *OCD* 545, s.v. "Eudemus") and Meno, of medicine (*OCD* 933, s.v. "Meno"; *DSB* 6.421, in s.v. "Hippocrates"). But none of these works survive (except possibly a papyrus fragment of Meno's history of medicine). These Aristotelian historical interests continued into the Roman period.

273. Aristotle, *On the Generation of Animals* 760b.

274. Lloyd 1981: 289.

275. *DSB* 1.264 (in s.v. "Aristotle"). Examples of Aristotle's use of vivisection: Aristotle, *On Respiration* 9.3.471b, *History of Animals* 3.12.519a, *On the Movement of Animals* 8.708b. Aristotle's illustrated eight-volume treatise *On Dissection*, however, was not preserved (see French 1994: 40–43).

276. Though tracking a similar path of progress was the increasingly scientific study of logic and language: see Russo 2003: 218–24; J. Barnes 1997; and *OCD* 839–40 and 855 (s.v. "linguistics, ancient" and "logic"). On the entry level logic taught in ancient schools: Huby 2004.

277. The link between state support and scientific progress during this period is most effectively illustrated in Schürmann 1991 (technological sciences) and von Staden 1989 (medical sciences).

278. See, for example, Rawson 1985: 11, 13–18. In the most direct case, scholars and scientists were forcibly expelled from Alexandria for political reasons, by the hostile (and ironically named) Ptolemy the Dogooder [Euergetes II] in 145 B.C. (e.g. Athenaeus, *The Dinnersages* 4.184b-c, who suggests this actually spread science *education* more widely, as fleeing scholars set up schools elsewhere), but this policy did not continue beyond his death in 116 B.C., and scholarship subsequently returned there.

279. Including a substantial revival of Aristotelian studies, spearheaded by Andronicus of Rhodes, who at Athens in the middle of the 1st century B.C. edited, collated, and systematized Aristotle's works, producing a definitive edition that was widely influential. See Gottschalk 1987 (with *OCD* 86 and 238, s.v. "Andronicus" and "Boethus (4)").

280. That society was on the brink of a Scientific Revolution: As argued in Edelstein 1952: 602–04. Lloyd concurs (see following note).

281. See Lloyd 1973: 154–78. For the decline of scientific medicine beginning in the 3rd century A.D. see Kudlien 1968, Nutton 2013: 299–317, Heinz 2009, and Mazzini 2012. For a similar decline in astronomy: Eastwood 1997. For the chaos of the 3rd century see my relevant note in chapter 1.1.

282. Edelstein 1952: 596–602 surveys the lack of direct institutional support for scientific research in antiquity, but he slights the considerable admiration and appreciation it received (an oversight we will remedy in this and the following chapter).

283. State support for doctors: On this fact see chapter eight of Carrier 2016.

284. Lucian, *On Attachés for Hire* 4 (usually known by the more contrived title *On Salaried Posts in Great Houses*). Though Lucian seems to ridicule those who take such work, his satire is more a complaint about how much the job sucks than an attack on those who take it. Hence when he himself took a salaried position for the state he had to write an *Apology* for his previous satire, arguing his original intent was to warn others like him against taking a bad arrangement (cf. *Apology* 3), because the private rich were often ridiculous whereas the government always offers respectable employment (cf. *Apology* 11–12).

285. That doctors could get rich through public and private practice is attested in, e.g., Pliny the Elder, *Natural History* 29.5.6–8 (and see, again, chapter eight of Carrier 2016). That engineers could receive generous pensions for their service is attested in, e.g., Vitruvius, *On Architecture* 1.pr.2–3 (note also the financial success of Galen's father who was an engineer, as discussed in chapter seven of Carrier 2016).

286. Though most professionals probably got most of their original work done in their retirement, as suggested by, e.g., Vitruvius, *On Architecture* 1.pr.1–3; Seneca, *Natural Questions* 3.pr.1–4 and *On Leisure* 4.1–5.7 (= *Dialogues* 8.4.1–8.5.7); Pliny the Elder, *Natural History* pr.18; Quintilian, *Education in Oratory* 1.pr.1 and 1.12.12; and Galen, On My Own Books 2 (= Kühn 19.17–18) and On Exercising with the Small Ball 2 (= Kühn 5.900–01).

287. For the following sections on the history of ancient science and technology, required reading on all subjects and fields includes Irby-Massie 2016, Russo 2003, and Rihll 1999. Valuable references adding to those include: Oleson 2008; Irby-Massie & Keyser 2002; Lloyd 1973; Sarton 1959; and Cohen & Drabkin 1948. More specific references will be cited below.

Section 3.2 Scientific Medicine up to the Roman Era

288. A good survey of medical sectarianism is provided in Nutton 2013: 149–53 (Empiricists); 191–206 (Methodists), 170–73 & 207–21 (Dogmatists), and 149 and 191 (various other sects). Nutton traces many lesser known medical writers in the historical development of their respective sects, whereas I will largely ignore these and the history of the sects and focus on the most notable contributions to medical science as a whole.

289. For general context and scholarship on ancient medical science generally see: Nutton 2013; Littman 1996; Scarborough 1993 (which supplements and updates Scarborough 1969); Lloyd 1973: 75–90; and *OCD* 79–82, 441–

42, 444, 451, 468, 501–02, 638–39, 712–13, 919–23, 952–53, 1040–41, 1089–90, 1122–23, 1414–15, 1562 (s.v. "anatomy and physiology," "dentistry," "diagnosis," "dietetics," "disease," "embryology," "gynaecology," "humours," "medicine," "midwives," "ophthalmology," "pathology," "pharmacology," "surgery," and "vivisection"). On ancient pharmacology: Everett 2012, Scarborough 2010, Schmitz & Kuhlen 1998, and Riddle 1986. On "veterinary medicine" see *OCD* 1545–46 and summary and sources in Rihll 1999: 132–36. On psychology: *OCD* 502–03 and 881–82 (s.v. "emotions" and "madness"), with P.N. Singer 2013, Roccatagliata 1986, and Siegel 1973.

290. Nutton 2013: 72–86 and Siegel 1968: 196–359 discuss ancient humoral theory in detail.

291. See Jackson 1988: 68, 80, 112–13, 172–73; Nutton 1983 and 2000b; and note below on Varro.

292. See James & Thorpe 1994: 38–41. Pliny the Elder, *Natural History* 25.94.150, for example, discusses painkillers and sedatives.

293. For example, see the extensive list of recognized antiseptic agents in Celsus, *On Medicine* 5.19.1–28. Galen recommended pitch and thick wine (according to extant passages from his Commentary on the 'Medical Practice' of Hippocrates, cf. Lyons 1963: 107, 111). The Romans also knew that water is purified by boiling: Pliny the Elder, *Natural History* 31.23.40.

294. Varro, *On Agricultural Matters* 1.12.2–3, who says "certain animals grow" in swamps "that are too small to be seen and float in the air, entering the body through the mouth or nose, causing serious diseases." For discussion: Sarton 1959: 409–10. These 'seeds' could also be imagined as mutating chemicals in air, water or food, a theory articulated in Lucretius, *On the Nature of Things* 6.1090–1144, and debated in Plutarch, *Tabletalk* 8.9 (= *Moralia* 731e and surrounding, where the speaker Diogenianus rejects the theory, but then Plutarch and his medical friend Philo defend it). Breath and bodily fluids were also known to be contagious for some diseases and not others (Pseudo-Aristotle, *Problems* 1.7.859b, 7.8.887a). On these various ideas see Nutton 1983.

295. *OCD* 1 and 370–71 (s.v. "abortion" and "contraception").

296. I will only survey the best known. For a more complete list of ancient medical writers, see *EANS* 1006–11 (s.v. "medicine") and 1013–19 (s.v. "pharmacy").

297. *DSB* 4.105–07; *EANS* 255–57; *OCD* 453 (s.v. "Diocles (3)"). For references on Hippocrates see Appendix B. For Diocles, Praxagoras, and the development of the life sciences between Hippocrates and the early Aristotelians see van der Eijk 2005.

298. Other pupils of Aristotle also contributed to botany and mineralogy (see section 3.5).

299. *DSB* 11.127–28; *EANS* 694–95; and *OCD* 1205. For Praxagoras and Diocles and other medical writers of the same period see Nutton 2013: 116–29. Ancient diagnostic use of the pulse was always more divination than science, but it nevertheless increased in sophistication over subsequent centuries, as summarized in an extant textbook on the subject by Marcellinus in the 2nd century A.D. See: *EANS* 526–27; *OCD* 896 (s.v. "Marcellinus (1)"); and Christ 1974; with discussions of the least scientific aspects of this 'science' in Barton 1994a: 133–68 and Kuriyama 1999.
300. *EANS* 59.

301. For the following see: *DSB* 6.316–19, *EANS* 387–90, and *OCD* 677–78; and most comprehensively von Staden 1989. Also, a good survey of the scientific accomplishments of Herophilus and his pupil Erasistratus (discussed next) can be found in Longrigg 1981. And on their legacy up to Galen on the study of the nervous system: von Staden 2000. And gynecology: Bliquez 2010.

302. These Herophileans and their research continued in every century up to the mid-1st A.D.: see von Staden 1989: 445–578 (which includes scientists not listed in the *OCD*). Among them: Andreas (*OCD* 85, *EANS* 77–78); Antonius Musa (*OCD* 113, *EANS* 101); Apollonius Mus (*EANS* 111–12); Bacchius of Tanagra (*OCD* 220, *EANS* 187–88); Callimachus (*OCD* 267, fourth entry, and *EANS* 462); Chrysermus (*OCD* 315–16, *EANS* 473); Heraclides (*OCD* 665, fourth entry, and *EANS* 367); Mantias (*OCD* 894, *EANS* 525–26); Philinus (*OCD* 1127, *DSB* 10.581, *EANS* 645–46); and Zeno (*OCD* 1588, fourth entry, and *EANS* 846). Pretty much all their vast work over the centuries was not preserved through the middle ages.

303. *DSB* 4.382–88; *EANS* 294–96; *OCD* 532–33; von Staden 1997b; and Longrigg 1981: 155–64, 177–85. On the innovative work of Herophilus and Erasistratus (and Eudemus) see Nutton 2013: 130–41. Nutton 2013: 142–59 also surveys other lesser known medical writers before the Roman period that I do not discuss (see also von Staden 1996: 91ff. for Erasistratus and some of his known successors). 304. For examples of his use of mechanical models see Vegetti 1995 and von Staden 1996: 91–98.

305. Eudemus: *EANS* 308.

306. Apollonius of Memphis: *EANS* 92 and 113–14.

307. Hegetor et al.: *OCD* 652–53 and *EANS* 359, with von Staden 1989: 445–45 (n. 1), 512–14 and P. Fraser 1972: 1.363–64 (with 2.536–39). None of his work survives.

308. *OCD* 434 (s.v. "Demetrius (21)") and *EANS* 232 with von Staden 1989: 506–11. None of his many books survive.

309. *OCD* 466–67 (s.v. Dioscurides (2)") and *EANS* 270, with von Staden 1989: 519–22 (and not to be confused with the later Dioscorides, discussed below). None of his many books survive. Scarborough 2012 discusses Phacas as well as Philotas and Olympus, two other medical scientists in Cleopatra's court, who also wrote on scientific subjects and none of whose writings survive.

310. Most thoroughly argued in Marasco 1998 (who discusses several other medical researchers of the period, as well as parallel activity in astronomy, geography, philology, and other fields; see also Scarborough 2012). Fraser also argued for a revival of medical research in Alexandria under Cleopatra and suggested this may have been the legacy of the highly-revered work of Heraclides the Herophilean (see above) in the early 1st century B.C. (P. Fraser 1972: 1.361–63, with 2.536–38).

311. Involving several scientists we know very little about, from the late 3rd century B.C. to the 2nd century A.D. See note above on the Herophileans; and *OCD* 288, 896, 1352 (s.v. "Cassius (1)," "Marcellus" [of Side], "Serapion (1)") with corresponding entries in *EANS* 207–08, 530, 733.

312. *OCD* 120 (s.v. "Apollodorus (4)"); *EANS* 106.

313. *OCD* 123, 124 (s.v. "Apollonius (8)" and "Apollonius (10)") and *EANS* 111–12, 113; with Potter 1993 and von Staden 1989: 455–56, 540–54. I am omitting doctors only known to have written commentaries, e.g. *OCD* 1591 (s.v. "Zeuxis (2)"; cf. *EANS* 848), or to have abandoned scientific for magical thinking, e.g. *OCD* 1580 (s.v. "Xenocrates (2)"; cf. *EANS* 836–37), or when we know too little of their contributions to science.

314. Antiochis: *EANS* 94.

315. *OCD* 202 (s.v. "Attalus III"; cf. *EANS* 179–80). He eventually granted his kingdom to Rome in his will, one of the few occasions of ostensibly peaceful annexation. Both this Attalus and the Mithradates mentioned next were also said to have tested poisons on condemned criminals (Galen, *On Antidotes* 1.1), which is also alleged of queen Cleopatra (Plutarch, *Antony* 71), who is also reported as having a working knowledge of poisons and chemical tricks (cf. Cassius Dio, *Roman History* 51.11; Pliny the Elder, *Natural History* 9.58.119–121 and 21.9.12). Though the stories of her experiments on humans are doubted (e.g. Marasco 1998: 49), they may embellish reports of genuine scientific activity by doctors in her court (and the same might be said for Attalus and Mithradates).

316. See *OCD* 1179 (s.v. "Pompeius Lenaeus"; cf. *EANS* 684) with 963–64 (s.v. "Mithradates"; cf. *EANS* 557–58), and Pliny the Elder, *Natural History* 25.3.5–7. For more sources and discussion of the scientific activities of Attalus and Mithradates (and other kings) see Marasco 1998: 52 (on Cleopatra: 50–53). On Mithradates, see also Mayor 2011b.

317. *OCD* 777 (s.v. "Juba (2) II"); *EANS* 441–42.

318. Asclepiades of Bithynia: R.M. Green 1955, Rawson 1985: 84–85 and 171–78, Scarborough 1993: 41–42, and Nutton 2013: 170–73, 190; *DSB* 1.314–15, *EANS* 170–71, and *OCD* 180 (s.v. "Asclepiades (3)"); and (for a reconstruction of his medical theories) Vallance 1990 and 1993.

319. Galen equated the Asclepiads with the Epicureans as advancing similar theories opposed to his own, e.g. Galen, *On the Uses of the Parts* 1.21 (= M.T. May 1968: 104–05). However, modern research has found that much of what Pliny the Elder says about Asclepiades (e.g. *Natural History* 26.7.12–26.9.20) is untrustworthy or demonstrably false, and though what Galen reports (e.g. Galen, *On the Natural Faculties* 1.14 = Kühn 2.45) is more reliable, it cannot be completely trusted either.

320. The Asclepiads were particularly interested in pharmacological research and several of them within a century of their founder had produced books on the subject that were well-regarded by Dioscorides (*DSB* 4.120, in s.v. "Dioscorides"). It is likely the Herophilean physician Alexander Philalethes was a pupil of Asclepiades, and combined his teachings with Herophilean principles and interests toward the end of the first century B.C. (cf. *OCD* 60, s.v. "Alexander (15) Philalethes" with *EANS* 56 and von Staden 1989: 532–39). Another pupil (?) of Asclepiades wrote on chronic diseases (*OCD* 1454, s.v. "Themison"; cf. *EANS* 782–83), and his pupil (?) in turn claimed to have established the Methodist sect *OCD* 1467 (s.v. "Thessalus (2)"; cf. *EANS* 804–05). Nutton 2013: 191–206 treats extensively of the rise of the Methodist sect, and the many medical writers associated with it, which I omit for lack of concrete examples of scientific contributions (until Soranus, discussed below).

321. Heraclides of Tarentum: *EANS* 370–71.

322. Hicesius: *EANS* 396.

323. Zeuxis Philalethes: Strabo, *Geography* 12.8.20, says it was a huge school. This benefaction was possibly commemorated on a Laodicean coin series at the time: *OCD* 1591 (s.v. "Zeuxis (3)"; cf. *EANS* 849) with von Staden 1989: 459–62, 529–31 and Benedum 1974. Among the related coins: *Sylloge Nummorum Graecorum* 9 (1964), pl. 125, no. 3855 and 3836/7 (which date between 27 and 7 B.C.).

324. Demosthenes Philalethes: See von Staden 1989: 570–78.

325. Sostratus of Alexandria: *OCD* 1386; *EANS* 754. He wrote on surgery, gynecology, and animals (and on the latter, see the coming discussion in section 3.5). And he is one of several scientists associated with the reign of Cleopatra (P. Fraser 1972: 1.363, with 2.537; Cleopatra's support of science will be discussed in the next section).

326. Alexander of Laodicea: *EANS* 56.

327. Meges of Sidon: *EANS* 538.

328. Since sources and scholars disagree whether Athenaeus dates to the late 1st century B.C. or mid-1st century A.D.

329. Nutton 2013: 207–08 with *DSB* 1.324–25, *EANS* 176–77, and *OCD* 195 (s.v. "Athenaeus (3)").

330. Aretaeus of Cappadocia: *DSB* 1.234–35; *EANS* 129–30; *OCD* 147; and Scarborough 1993: 43–44 and Nutton 2013: 210–11. Parts of this latter work survive. Aretaeus was either a colleague of Nero's personal physician Andromachus (who wrote on pharmacology), or a contemporary of Galen (again, our sources are so poor that scholars cannot agree). Other Pneumatists worked in the 1st century A.D. about whom we know little and whose works are lost (e.g. *OCD* 676 and 1167, s.v. "Herodotus (2)" and "Pneumatists"; cf. *EANS* 383–84). For sources on the Pneumatist sect see von Staden 1989: 541, n. 22, and Oberhelman 1994.

331. Rufus of Ephesus: For the following: *DSB* 11.601–03; *NDSB* 6.290–92; *EANS* 720–21; *OCD* 1298; also M.T. May 1968: 29–30; Scarborough 1993: 44–46; Sideras 1994; Thomssen 1994; Nutton 2013: 214–16.

332. Similar indications of a growing interest in occupational medicine are indicated by Pliny the Elder's concern for the respiratory health of metalworkers in *Natural History* 34.50.167 (other examples in Nutton 2013: 27). Even without such examples, the claim that "the working man" and "the occupational disease" were "ignored in medical science" until the 18th century (Farrington 1946: 29) is unfounded.

333. Paccius: *EANS* 95.

334. Largus: Nutton 2013: 175–78, *OCD* 1331, and *EANS* 728–29. One of his treatises on *Prescriptions* is extant (see Hamilton 1986). Nutton 2013: 181–82 and 250 discusses a few other imperial medical writers about whose work we know much less.

335. Agathinus: Nutton 2013: 208–09 with *DSB* 1.74–75, *OCD* 35–36, *EANS* 42–43.

336. Archigenes: Nutton 2013: 209–10 with *DSB* 1.212–13, *EANS* 160–61, and *OCD* 140.

337. Pedanius Dioscorides: *EANS* 128–29.

338. Riddle 1993: 103–13 and Nutton 2013: 178–81; *OCD* 465–67 (s.v. "Dioscorides (2)"); *EANS* 271–73; and *DSB* 4.119–23, which adds that "numerous treatises in Greek and Latin are falsely attributed to Dioscorides" (4.119), and although numerous later interpolations also entered his authentic text, these can usually be identified through comparison of widely divergent manuscript traditions. Dioscorides did write other books on pharmacology besides *On Medical Materials*, but none survive. He should *not* be confused with Dioscurides Phacas, the medical writer under Cleopatra (as perhaps in Marasco 1998: 43–47).

339. Pliny the Elder, *Natural History* 25.4.8; see *DSB* 4.120 (in s.v. "Dioscorides"). Crateuas: *OCD* 391 and *EANS* 491; Dionysius: *EANS* 264; Metrodorus: *EANS* 553.

340. *OCD* 444 (s.v. "diagrams") and Netz 2010. For examples in mathematics, metaphysics, and astronomy see Obrist 2004. Books on mechanics (e.g. those of Hero, Vitruvius, Philo) frequently refer to accompanying drawings and diagrams (you can see analysis of extant examples in Lefevre 2002 and Leeuwen 2014), as do some medical books (e.g. Apollonius of Citium included instructional diagrams of his procedures for treating dislocations, cf. Potter 1993: 117 and Nutton 2013: 145). Likewise engineering (e.g. Meissner 1999: 247–48; Heisel 1993). Ptolemy, *Harmonics* 3.94 implies all the sciences relied on such artwork, since "what is given by reason becomes both more teachable and better remembered by us with diagrams and figures." One can find many other examples in all fields (from medicine to geography to engineering). That even geometry texts included diagrams is confirmed by mathematical papyri recovered from Herculaneum (cf. De Falco 1923: 101–03). Aristotle had included drawings and diagrams in some of his works (e.g. Taub 2003: 103–14).

341. On the difficulty of faithfully copying and thus disseminating such visual data: Pliny the Elder, *Natural History* 25.4.8. Ptolemy, *Geography* 1.18 reports the same problem for copying maps, developing a system of map construction in response. Hero recognized the problem for engineering schematics and invented a pantograph as another remedy (see below).

342. *DSB* 4.120, 4.122 (in s.v. "Dioscorides").

343. Soranus of Ephesus: *DSB* 12.538–42, *EANS* 749–51, and *OCD* 1358; with Lloyd 1983: 168–200; Jackson 1988: 88–90, Scarborough 1993: 46–47, Hanson & Green 1994, Nutton 2013: 199–206; Bliquez 2010.

344. *OCD* 654, 933, 1396 (s.v. "Heliodorus (3)," "Menodotus (3)," "Statilius Crito"); cf. *EANS* 363, 549–50, 494–95. Nutton 2013: 262 discusses Crito's career. As usual, most of what these men wrote was preserved only in fragmentary quotations by later authors. Heliodorus also wrote a treatise *On Weights and Measures*, suggesting a rising medical interest in a subject usually treated by engineers. For more on Heliodorus see P. Fraser 1972: 1.363 (with 2.538).

345. Philumenus: *OCD* 1138; *EANS* 661–62. Only fragments of the named books survive.

346. Promotus: *OCD* 19; *EANS* 35.

347. Antyllus: *OCD* 114; *EANS* 101–02. See also P. Fraser 1972: 1.363 (with 2.537–38).

348. Sextus: *DSB* 12.340–41, *EANS* 739–40 and *OCD* 1358–59. There is no basis for Peter Green's assertion (P. Green 1990: 470) that the meticulous Hippocratic method of assembling case histories fell into disuse immediately after Hippocrates invented it. The empiricist sect relied almost exclusively on the method of carefully analyzing case histories, and other doctors employed them as well (Nutton 2013: 150–51; Mattern 2008: 27–47). We have no reason to believe medieval scribes would have preserved anyone's medical case notes, when they did not even

deign to preserve a single empiricist medical book. Even some of the case histories of Rufus survive only in Arabic (Nutton 2013: 214). Galen's medical notes had already been lost in a fire and thus were not transmitted to us (refs. in Carrier 2016: 55 n. 135).

349. Marinus: M.T. May 1968: 31–34; *EANS* 532 and *OCD* 899. On the others: M.T. May 1968: 34–38; with: Quintus (*OCD* 1252; *EANS* 717), Satyrus (*OCD* 1323, third entry, there misdated as B.C. instead of A.D., an obvious typo; *EANS* 728), Pelops (*EANS* 634), Lycus (*EANS* 514), and Numisianus (*EANS* 584). See also *OCD* 79–82 (s.v. "anatomy and physiology"). On these and other scientists in the Roman revival of anatomical studies see Nutton 1993b: 15–19.

350. Nutton 2010.

351. Claudius Menecrates: Gourevitch 1970: 44; *EANS* 544. On the Menecrateans as a possible medical family spanning many generations see chapter 2.3. Galen complains that some medical quacks wrote "hundred volume works" (*On the Therapeutic Method* 1.4.12, cf. also Iskandar 1988: 175, §P.134,4–5) so we can't be sure of the scientific quality of the medical books by Claudius Menecrates.

352. Hermogenes of Smyrna: Nutton 2013: 216; *EANS* 379. The content of these books is unknown (see preceding note).

353. Heraclitus of Rhodiapolis: *EANS* 373. Of his books we don't even know the titles.

354. *EANS* 172. Her precise date is unknown. But the quality of her work in quotation rivals Soranus, yet neither Soranus nor Galen mention her; and conversely, the content of her work suggests her science predated the 3rd century crisis and subsequent Christianization. So most likely she dates to the early 3rd century.

355. Aspasia: Nutton 2013: 216–21 surveys several other likely medical writers of this period about whom we know almost nothing.

356. Analogous to the mysterious Menecrates is the equally mysterious author of the "Keskinto Inscription," name unknown but clearly an astronomer of considerable skill who surely must have written books (see *EANS* 469 and note at the end of chapter eight in Carrier 2016). Likewise the inscription of the otherwise-unknown engineer Nonius Datus, which is much too wordy and exciting to have come from a man who never wrote books (discussed in chapter 4.5). It is also unlikely the three attested "*physici*" in Roman inscriptions wrote nothing on scientific subjects (see chapter 2.3).

357. On Galen's fame: Nutton 1984b. For the rest: *DSB* 5.227–37; *NDSB* 3.91–96; *EANS* 335–39 (cf. 339–42); *OCD* 600–01; Nutton 2013: 222–35; Hankinson 2008; Mattern 2008 and 2013; Riddle 1993: 113–17; Lloyd 1973: 136–53; Scarborough 1970: 303–05; Bowersock 1969: 59–75; Siegel 1968: 4–26. See also: Whitmarsh et al. 2009. Galen also wrote valuable works in language, logic, and scientific method, few of which survive (cf. Nutton 2013: 228). Galen also wrote a treatise on augury, omens, astrology, and dream interpretation (cf. Galen, *On the Natural Faculties* 1.12 = Kühn 2.29) which is lost, but appears to have presented them positively (much as Ptolemy did for astrology). On Galen's medical theories: Nutton 2013: 236–53.

358. Central works in this category include Galen's monumental multi-volume sets *On the Uses of the Parts* and *On Conducting Anatomical Investigations*.

359. Nutton 2013: 238 surveys some of Galen's scientific discoveries. On his failure to develop correct theories of circulation and respiration see discussion and notes in section 3.9.II.

360. See discussions of his epistemology in section 3.7 and theory of respiration in 3.9.II.

361. As demonstrated throughout Siegel 1968, Galen expressed doubts about some of his own theories and often distinguished proofs from plausible speculations in a way later overlooked.

362. *OCD* 600 (in s.v. "Galen"). For an exhaustive survey of the wide array of anatomical and physiological experiments conducted by Galen see Debru 1994, along with Tieleman 2002, Rocca 2003, and Siegel 1968, 1970, and 1973.

363. Galen, *On the Natural Faculties* 1.13 (= Kühn 2.30–40), analyzed in Siegel 1968: 126–34.

364. Galen, *On the Natural Faculties* 3.4 (= Kühn 2.155–57).

365. Galen, *On the Natural Faculties* 3.7 (= Kühn 2.162–63).

366. Galen, *On My Own Books* 2 (= Kühn 19.20–22).

367. See Galen, *On the Uses of the Parts* 14.4 (= Kühn 4.153 = M.T. May 1968: 626) and On Conducting Anatomical Investigations 11.12.

368. For example, see Galen, *On the Uses of the Parts* 1.3 (= M.T. May 1968: 70–71) and On Conducting Anatomical Investigations 6.1 (= Kühn 2.538).

369. Quote and sample of sources in von Staden 1995: 47. Galen discusses a partial list of the animals he had systematically dissected in *On Conducting Anatomical Investigations* 6.1 (= Kühn 2.532–40), specifically adding that he had not dissected insects. More animals he dissected are mentioned in Galen, *On Conducting Anatomical Investigations* 7.11 (= Kühn 2.623–24).

370. Galen, *On the Uses of the Parts* 17.1 (= M.T. May 1968: 724–25) and *On Conducting Anatomical Investigations* 7.10 (= Kühn 2.619–23). See discussion in French 1994: 190–91 and Hankinson 1988.

371. Galen, *On the Natural Faculties* 1.14 (= Kühn 2.45–51).

372. Galen, *On the Natural Faculties* 1.14 (= Kühn 2.55–56). Grain storage manuals now recommend plastic liners over concrete floors to prevent this phenomenon (e.g. Hellevang 1998).

Section 3.3 Scientific Astronomy up to the Roman Era

373. For context and scholarship see Neugebauer 1975, Lloyd 1973: 53–74 (with 33–52); van der Waerden 1963; *OCD* 188–90 (s.v. "astronomical instruments" and "astronomy"), and 910–11 and 1483 (s.v. "mathematics" and "time-reckoning"). For the mathematical background (across all fields of inquiry, not just astronomy): Cuomo 2001.

374. On ancient geography see *OCD* 611–12 (s.v. "geography"), with Dueck 2012, Hubner 2000, Rihll 1999: 82–105, French 1994: 114–48, and Gorrie 1970. Ancient meteorology also included geological phenomena such as earthquakes: Taub 2003 with *OCD* 482 and 941–42 (s.v. "earthquakes" and "meteorology"); cf. Aristotle, *Meteorology* 1.1 (338a-339a); Seneca, *Natural Questions* 2.1.2–5.

375. Russo attempts to argue that Hellenistic astronomers had actually achieved an astrophysical dynamics rivaling Newton's (Russo 2003: 231–42, 282–320), but though this maverick effort is clever, it is ultimately flawed and unconvincing. It's not impossible. But it is very unlikely.

376. *DSB* 1.338–39, *EANS* 183, and *OCD* 214 (s.v. "Autolycus (2)"), whose treatise *On Risings and Settings* is the earliest known scientific star catalogue. For pre-Aristotelian astronomy see Appendix B (esp. Eudoxus and Callippus). After Aristotle I'll only remark on the best known astronomers; for a more thorough list of all known astronomers in antiquity, see *EANS* 995–96 (s.v. "astronomy").

377. Empirical observations of varying distances for the planets and moon continued into the Roman period (cf. Cohen & Drabkin 1948: 103–05 and 142, quoting Ptolemy and his contemporary Sosigenes).

378. Dicaearchus: *OCD* 447; *EANS* 246.

379. Pliny the Elder, *Natural History* 2.65.162.

380. M.J. Lewis 2001b: 157–66, 335–39 (on Dicaearchus: 158–62).

381. Euclid: *DSB* 4.414–59, *EANS* 304–06 and *OCD* 544; and see discussion in *DSB* 13.321–25 (s.v. "Theon of Alexandria"). Besides the *Elements* Euclid also wrote several other books on geometry, only one of which survives intact (the *Data*, which includes theorems relevant to algebra), although a few others survive as fragments in Arabic translation. Regardless of whether other extant works in optics, catoptrics (i.e. reflection), and harmonics are his, he probably did write on those subjects.

382. Strato of Lampsacus: *Diogenes Laertius, Lives and Opinions of Eminent Philosophers* 5.58 (as noted in chapter 2.5, the honor of this epithet was awarded him throughout ancient literature). He also wrote on logic, ethics, and technology, among many other subjects. For the rest of the present discussion, see: *EANS* 765–66; *NDSB* 6.540; *DSB* 13.91–95; *OCD* 1406 (s.v. "Straton (1)"); Lloyd 1973: 15–20; and sources and discussion in Berryman 1996 and Desclos & Fortenbaugh 2011.

383. A prototype of inertial theory in atomism can be seen in Lucretius, *On the Nature of Things* 2.62–166 and 2.184–332; and in Seneca, *Natural Questions* 7.14.3–5.

384. Observing falling stones and streams of water: Reported (though perhaps without fully comprehending the original argument or context) in Simplicius, *Commentary on Aristotle's 'Physics'* 5.6.916; and Simplicius, Commentary on Aristotle's 'On the Heavens' 1.8.267.29 and 1.8.269.4.

385. Aristarchus: For the following: *DSB* 1.246–50; *EANS* 131–33; *OCD* 153; Heath 1913.

386. Plutarch says Aristarchus proposed heliocentrism as "only a hypothesis" but that Seleucus "demonstrated it" (*Platonic Questions* 8.1 = *Moralia* 1006c). He does not say how. Though heliocentrism never dominated, it was not ignored, e.g. Panchenko 2000 argues its challenges continually led to improvements in geocentric models. See also discussion in section 3.5.

387. Eratosthenes: For the following: *DSB* 4.388–93, *EANS* 297–300, and *OCD* 533–34. Eratosthenes was also a published poet and philosopher and frequently combined science and literary scholarship (see Pfeiffer 1968: 152–70).

388. On ancient explorers and exploration in relation to scientific geography see Appendix A.

389. When converting measures in ancient stades (or "stadium lengths," similar to Americans measuring distances in "football fields") to modern miles I follow the critical conclusions of Engels 1985 and Pothecary 1995 that the stade used by scientific authors measured somewhere between 600 to 610 feet (or roughly 8.75 stades per modern mile).

390. It was possibly in connection with his chronographic work that Eratosthenes wrote on mathematical and calendrical problems in astronomy (cf. Geminus, *Introduction to Astronomy* 8.24). His chronographic work was subsequently extended and improved by Apollodorus of Athens in the following century (*OCD* 120, s.v. "Apollodorus (5)").

391. Apollonius: For the following: Fried & Unguru 2001; *EANS* 114–15, *DSB* 1.179–93, *NDSB* 1.83–85, and *OCD* 122–23.

392. Eutocius, *Commentary on the 'Conics' of Apollonius* 2.170 (early 6th century A.D.).

393. On helix and mechanics: Russo 2003: 98, 120. For Archimedes see discussion in section 3.4.

394. Robotic flute: M.J. Lewis 2000: 352–54 (and 1997: 49–57 & 86–88).

395. Gears: M.J. Lewis 1997: 24, 50.

396. Epicyclic and eccentric models: These alternative models of planetary motion were discussed in chapter 2.7.

397. Dionysodorus: *DSB* 4.108–10; *EANS* 266.

398. Perseus: *DSB* 10.529–30, *EANS* 636, and *OCD* 1111 (s.v. "Perseus (3)").

399. Zenodorus: *DSB* 14.603–05, *NDSB* 1.83–85, *EANS* 845, *OCD* 1588. Even Quintilian shows a sound grasp of the uses and principles of isoperimetry and gives several examples of why generals, historians, surveyors, and lawyers need to learn it (*Education in Oratory* 1.10.39–45). Examples of its application and discussion are found in extant surveying manuals from the early Roman empire (e.g. B. Campbell 2000: 12–13) and it found use even in biology (e.g. Cuomo 2000: 57–90 for its use in apiology; Aristotle, *Posterior Analytics* 1.13.79a for its use in medical physiology).

400. Dositheus and Diocles: *DSB* 1.187 (in s.v. "Apollonius of Perga"). Dositheus: *DSB* 4.171–72; *EANS* 277; *OCD* 477. Diocles: *DSB* 4.105 (updated in *DSB* 15.115–18); *EANS* 255; and *OCD* 453 (s.v. "Diocles (4)"). For Diocles' extant treatise on burning mirrors see Toomer 1976; and for a broader history of the scientific study of them in antiquity see Acerbi 2011. On ancient sundial technology see Evans & Berggren 2006: 34–38, Evans 1999: 243–51, and Gibbs 1976 (plus other sources on sundial technology mentioned in following notes).

401. Building on predecessors: Apollonius of Perga, *Conics* 1.2.4. His predecessors included the 4th century founders of the study of conics: first Menaechmus (*OCD* 929, second entry; *EANS* 542–43), then Aristaeus (*DSB* 1.245–46; *EANS* 130–31) and Euclid (above); and from the early 3rd century, Nicomedes, who wrote on the mathematical uses and properties of conchoids (i.e. three-dimensional spirals, cf. *DSB* 10.114–16; *EANS* 580; *OCD* 1015, s.v. "Nicomedes (5)").

402. *OCD* 1342 (s.v. "Seleucus (5)") and *EANS* 730. On ancient lunisolar tidal theory (which was studied and developed further after Seleucus) see: Pliny the Elder, *Natural History* 2.99.212–218 and 2.102.221, with: Cicero, *On Divination* 2.34 and On the Nature of the Gods 2.7.15–16; Seneca, On Providence 1.4; Cleomedes, *On the Heavens* 156; and Ptolemy, *Tetrabiblos* 1.2.3–6; as well as Strabo, *Geography* 3.5.8 and 1.1.8–12, who confirms that the role of the moon had already been established by Eratosthenes shortly before Seleucus, who probably discovered the role of the sun (see Kidd 1988: 522–25, 759–65, 772–92). On ancient tide theory and its significance see Russo 2003: 305–15 and 360–65, though some of his conjectures exceed the evidence.

403. Strabo, *Geography* 2.5.10. See *EANS* 490 and *OCD* 390–91 (s.v. "Crates (3)").

404. Hipparchus: For the following: Neugebauer 1975: 1.274–343 with *DSB* 15.207–24, *EANS* 397–99, and *OCD* 685–86 (s.v. "Hipparchus (3)").

405. These coins appeared only in the Roman era, not during his life, a fact we will discuss in chapter 4.3. For scholarship see Schefold 1997: 418–19, 543 (Abb. 302) and in *DSB* 15.207–08 and 15.222 (in s.v. "Hipparchus").

406. On this poem by Aratus see discussion and notes in chapter four of Carrier 2016.

407. *DSB* 15.220 (in s.v. "Hipparchus") with Russo 2003: 281–82 and Netz 2003: 283–84. Combinatorial arithmetic involves factorials and permutations (the ability to calculate accumulating products and sums and determine the number of possible ways to arrange a collection), but we do not know how much of this Hipparchus studied or to what end (see Plutarch, *Tabletalk* 8.9 = *Moralia* 732f-733a; and the bibliography in *DSB* 15.223–24). We at least know the title of his treatise on what we now call gravity: *On Objects Carried Down by their Weight* [*Peri tôn dia Barutêta katô Pheromenôn*], cf. Simplicius, *Commentary on Aristotle's 'On the Heavens'* 1.8.264.25 (see Desclos & Fortenbaugh 2011: 313–52).

408. Hipparchus anticipating Galileo: *DSB* 7.136 (in s.v. "John Philoponus") and Simplicius, *Commentary on Aristotle's 'On the Heavens'* 1.8.264.25–265.6. However, Russo's attempt to argue that heliocentrism was embraced by both Hipparchus and Archimedes (Russo 2003: 78–89, 282–319) is flawed and unconvincing, e.g. Strato's theory of motion is more compatible with geocentrism than Russo allows, and many subsequent sources knew the work of Hipparchus and Archimedes yet never list them among the heliocentrists, despite the fact that they were far more famous than either Aristarchus or Seleucus, so their endorsement of the theory would have been too notable not to mention. I also do not believe Hipparchus has been correctly interpreted when Simplicius quotes him (indirectly from his lost *On Objects Carried Down by their Weight*) that bodies are heavier the higher they are (e.g. Wolff 1987: 100–05 and Wolff 1988: 489 n. 19, in reference to Simplicius, *Commentary on Aristotle's 'On the Heavens'* 1.8.265.10)—I suspect (for reasons too numerous to list here) that Hipparchus was actually speaking of the impact weight (we would say 'force') of dropped objects, not their static weight at elevation, hence following Strato's discovery that

falling objects accelerate regardless of mass (thus Alexander of Aphrodisias, as paraphrased in Simplicius, *Commentary on Aristotle's 'On the Heavens'* 1.8.265.29–266.4, clearly did not understand the Hipparchean explanation of the acceleration of falling objects, ibid. 1.8.264.25–265.6, nor did Simplicius, who had clearly never read Hipparchus himself). Though Wolff 1988 attempts to defend the interpretation of Alexander and Simplicius, I believe there are flaws in Wolff's argument as well, which I may explore in future.

409. Theory of light: Plutarch, *On the Face that Appears in the Orb of the Moon* 4 (= *Moralia* 921d-e). See discussion in section 3.5 (and related note in chapter 2.7).

410. Influencing Mithraism: Ulansey 1989; influencing messianic Judaism and thus Christianity: Charlesworth 1978. On the science of precession see Russo 2003: 315–16. "Precession" is the result of the earth's slow wobble (like a rotating top, though Hipparchus might have assumed it was the sphere of the stars that wobbled), which results in a regular shift in the observed positions of stars. As a result, the pole of the sky rotates in a circular arc over a period of roughly 26,000 years, with the effect that a solar year will begin with the rising of a different constellation roughly every 2200 years. This meant astrological signs shift on the calendar, an appalling yet revolutionary fact for astrologers, hence influencing all astral religions (and Pliny the Elder, *Natural History* 2.24.95, suggests Hipparchus wrote works on astrology).

411. Aristyllus: *DSB* 1.283; *EANS* 155–56. Timocharis: *OCD* 1483; *EANS* 812–13. Conon of Samos: *DSB* 3.391, *EANS* 486, and *OCD* 361 (s.v. "Conon (2)"); cf. Seneca, *Natural Questions* 7.3.3. The achievements of Hipparchus all but eclipsed his own contemporaries, hence we know very little about them, like Leptines (unknown but for a papyrus fragment of his introduction to astronomy, with illustrations, written around 165 B.C., cf. *NDSB* 4.271–72, *EANS* 505, and Evans & Berggren 2006: 10–12, 79); or Hypsicles of Alexandria: *DSB* 6.616–17 (with *DSB* 15.210, in s.v. "Hipparchus"), *EANS* 425, *OCD* 718, and Evans & Berggren 2006: 74, 79–80.

412. Either Hipparchus or subsequent astronomers before the 1st century A.D. could make eclipse predictions down to the hour according to Pliny the Elder, *Natural History* 25.5.10, although Ptolemy's system (perfected a century after Pliny) made prediction easier and more accurate.

413. Lunar mean distance: G.J. Toomer (in *DSB* 15.215, s.v. "Hipparchus"). The ratio holds regardless of the true earth radius (about 4000 miles), but Hipparchus was working from a slightly high value (roughly 4600 miles according to Eratosthenes), so 59 to 67 radii translated then to an absolute value for the earth-moon distance of 271,000 to 309,000 miles. The actual distance varies from 221,000 to 252,000. Remarkably close given the instruments available.

414. Though it is worth noting that his estimate of solar distance (2500 earth radii) and size (1880 earth volumes) are still impressive. This equated to over a million miles distant (actual is about 93 million) and over a hundred thousand miles in diameter (actual is about 870,000). These figures are given in Theon of Smyrna, Aspects of Mathematics Useful for Reading Plato 3.39.197 (though Theon does not state the Hipparchean value for the earth-sun distance, we can deduce it from the method and figures Theon records; Cleomedes, *On the Heavens* 2.1, gives a different amount, but Theon's more detailed report is more credible than this passing remark by Cleomedes, which was more vulnerable to error or textual corruption).

415. G.J. Toomer (in *DSB* 15.220, s.v. "Hipparchus"). See relevant example in section 3.9.II.

416. Theodosius: *DSB* 13.319–21, *EANS* 789–90, and *OCD* 1459 (s.v. "Theodosius (4)"). The technology of portable sundials would be greatly advanced under the Romans, who developed versions the size of a human thumb that could determine the hour of the day, at any time of year, for a variety of latitudes (the Roman invention of all-latitude sundials is attributed to "Andrias," a name possibly garbled in Arabic translation: *EANS* 77). See Arnaldi & Schaldach 1997, which includes a historical discussion and a recovered example. For other kinds of portable sundial see Dilke 1971: 70–73. Several geared sundial calendars have also been recovered of Byzantine date (M.T. Wright 1990) whose design could long predate extant finds. Their technology is similar to the Antikythera computer (Evans 1999: 267–70), and some are mechanically adjustable for latitude, so some ancient references we have to advances made in portable sundials could refer to devices like these.

417. *OCD* 455 (s.v. "Diodorus (4)"), *NDSB* 2.304–05, and *EANS* 247, not to be confused with the historian from Sicily. Only a fragment of the Alexandrian's work was preserved and only in Latin and Arabic, plus scattered quotations (see discussion in Edwards 1984: 152–82).

418. The idea that comets could be planetary bodies precedes even Aristotle, who argued against it (cf. Aristotle, *Meteorology* 1.4–7), but subsequent defenses of it became more sophisticated, most notably, around this time, in the lost works of Apollonius of Myndus (*EANS* 114; Seneca, *Natural Questions* 7.4 and 7.17, reporting in 7.19 that some Stoics agreed). Whatever its origin, a nearly correct theory of comets evolved and continued into the Roman period: see Diodorus Siculus, *Historical Library* 15.50.3; Manilius, *Astronomy* 1.867–75; Pliny the Elder, *Natural History* 2.23.91 and 94; and Ammianus Marcellinus, *Deeds of the Divine Caesars* 25.10.2. It was verified and defended by Seneca (cf. *Natural Questions* 7.22), who combined past records with his own observations of comets in 54 and 60 A.D. (cf. e.g. *Natural Questions* 7.17, 7.21.3–4, 7.23.1, 7.26.2, 7.28.3–7.29.3, etc.) and described the most advanced cometary theory of his time, very close to the modern view, in books 2 and 7 of the *Natural Questions*. See Heidarzadeh 2004; Keyser 1994; and Kidd 1988: 490–96 (with 1999: 184–88), as well as the background provided in *DSB* 12.309–10 (s.v. "Seneca, Lucius Annaeus").

419. Posidonius,: *DSB* 11.103–06, *EANS* 691–92, and *OCD* 1195–96 (s.v. "Posidonius(2)"). See also Edelstein & Kidd 1989, Kidd 1988, and Kidd 1999. In the *DSB*, Warmington's cynical conclusion that Posidonius was not influential is wholly untenable in light of copious evidence of his broad influence in literature throughout the early Roman empire, from Strabo, Livy and Diodorus, to Seneca, Plutarch, Pliny the Elder and Galen—and many others, as Warmington's own notes ironically demonstrate. Kidd's more moderate conclusion in the *OCD* is more reasonable, and well supported by evidence in Kidd 1999.

420. Strabo, *Geography* 16.2.10.

421. Galen, *On the Doctrines of Hippocrates and Plato* 8.1.14, using the word *epistêmonikôtatos*, the superlative of *epistêmonikos*, "capable of knowing, scientific" (*LSG* 660).

422. Seneca, *Moral Epistles* 90.20.

423. P. Green 1990: 644 (for Green's overly cynical picture of Posidonius in general: 642–46, 596–97). For more general aspects of the relationship of Stoicism to science see references in *DSB* 14.605–07 (s.v. "Zeno of Citium"), *EANS* 846–47, and *OCD* 1403–04 and 1587–88 (s.v. "Stoicism" and "Zeno (2)"). See also Carrier 2016 (index, "Stoicism").

424. Medicine: Kudlien 1970: 16 and Rawson 1985: 178, though this is disputed by Marasco 1998: 44–46 (and others cited there). Mechanics: Cuomo 2001: 164, though this is questioned by Kidd 1988: 714–16 (= F199b).

425. Strabo, *Geography* 3.1.5 (with Kidd 1988: 464 and Edelstein & Kidd. 1989: 115), which contains a reference to knowledge of lenses that magnify through refraction, attributed to Posidonius—in a discussion of atmospheric refraction (cf. also Cleomedes, *On the Heavens* 2.6 and Sextus Empiricus, *Against the Professors* 5.82) that bears comparison with later research by Ptolemy on exactly the same subject (see notes below). A century later Seneca mentions in passing lenses that magnify well enough to assist reading (*Natural Questions* 1.6.5–7). No scientific treatise on the subject survives from antiquity, although missing sections of Ptolemy's *Optics* may actually have included it (cf. Russo 2003: 331, with A.M. Smith 1996: 47–49), and there is archaeological and literary evidence that Romans may have started to experiment with lenses and magnification. See Dillon 1970 (with Kisa 1908: 355–59, Trowbridge 1930: 182–83, and Healy 1999: 147–50), Bastomsky 1972, Sines & Sakellarakis 1987, Enoch 1998 (with James & Thorpe 1994: 157–61), and Draycott 2013. Though skepticism is maintained by Plantzos 1997 and Krug 1987 (who correctly rebut, among other things, the notion that Nero had spectacles, though he may have used monocular or binocular sunshades; cf. also Disney et al. 1928: 43–65, though much of that is obsolete), and magnifying glasses may have been unknown to Galen, though he had seen microscopic art (*On the Uses of the Parts* 17.1 = M.T. May 1968: 731), which was not uncommon (e.g. Pliny the Elder, *Natural History* 7.21.85), as also microscopic texts (ibid. and Millard 2000: 169–70). On early references to using lenses to start a fire (e.g. Aristophanes, *Clouds* 768–75; Aristotle, *Posterior Analytics* 1.31.88a14–17; Theophrastus, *On Fire* 73) see Trowbridge 1930: 178–80, a property employed in Roman medicine to cauterize wounds (Pliny the Elder, *Natural History* 37.10.28). For a possible optical cauterizer recovered from antiquity see Plantzos 1997: 460. Likewise, magnifying *mirrors* were certainly well known and in use, both to magnify and burn, and their principles were scientifically understood (e.g. Plutarch, *On the Face that Appears in the Orb of the Moon* 17 and 23 = *Moralia* 930b and 937a; Seneca, *Natural Questions* 1.15.7–1.16.8; Pliny the Elder, *Natural History* 33.45.128–129; and sources cited in previous notes).

426. Arrian, *Art of War* 1.1.

427. See discussion of Seleucus above (tide theory), including subsequent note (size of the earth), and earlier note (sizes and distances of sun and moon). Posidonius speculated several different estimates for the size and distance of the sun and moon, but his best were: 57 million miles for the distance of the sun (actual: 93 million), 344,000 miles for the diameter of the sun (actual: 870,000), 229,000 miles for the distance of the moon (essentially correct, which casts doubt on the claim that Posidonius found the moon's diameter to be 4500 rather that its actual 2200 miles: see Cleomedes, *On the Heavens* 1.7, 2.1, and 2.3, and Pliny the Elder, *Natural History* 2.21.85).

428. Besides 20,500 miles, Posidonius also said the earth could be as much as 27,500 miles in circumference, a result actually *closer* to the truth than Eratosthenes'. For the best account of what happened to lead subsequent experts to prefer the lower value see M.J. Lewis 2001b: 143–56 and 332–34 (substantially correcting Taisbak 1974), who also demonstrates that no one in antiquity believed these figures were anything more than approximate and hypothetical. Ptolemy, for example, explicitly said he invented the system of latitude and longitude (essentially the same one we use today, although with the mean line now moved from Alexandria to Greenwich) precisely to bypass the problem of not having an accurate measure of the earth's diameter (and he called upon future scientists to therefore develop better measures of it).

429. The Posidonius machine: Cicero, *On the Nature of the Gods* 2.34. Novara 1996 provides a literary historical analysis of this passage. The seven known planets were: earth, moon, sun, Venus, Mars, Jupiter, and Saturn.

430. Various kinds of armillary sphere were constructed during and after the Renaissance—and no doubt in antiquity, as various texts and depictions on ancient coins, reliefs, and mosaics attest. On ancient astroglobes and armillaries see Evans & Berggren 2006: 27–34 and 47, Beck 2006: 120–28, Evans 1999: 237–43, Murschel 1995, and Aujac 1993: 157–78. Arnaud 1984 extensively surveys the iconography of globes in ancient art (on armillary and other astronomical spheres specifically: 59–77). For the best recovered depiction of an armillary sphere, from an early Roman villa in Solunto, Sicily (late 2nd or early 1st century B.C.): von Boeselager 1983 and Evans & Berggren 2006: 32. Most armillary spheres did not include the planets, but only the position of ecliptics and other astronomical lines with respect to an observer's position on earth, adjustable by season. Few added the movement of the sun or moon. Very few did include all the planets (thus luniplanetary). Though we have no visual representations of these from antiquity, we have literary descriptions. Some of these machines were automated by water power, as attested in Galen, *On the Uses of the Parts* 14.5 (= M.T. May 1968: 627) and Pappus, *Mathematical Collection* 8.2.1026.

431. Mentions or descriptions of these and similar orreries and armillary spheres include: Cicero, *On the Republic* 1.14.21–23, *Tusculan Disputations* 1.25.63, *On the Nature of the Gods* 2.34.87–88; Ovid, *Fasti* 6.270–77; Geminus, *Introduction to Astronomy* 5.62–63, 6.21, 12.23, 12.27, 16.10–12; Aulus Gellius, *Attic Nights* 3.10.3; Galen, *On the Uses of the Parts* 14.5 (= M.T. May 1968: 627); Sextus Empiricus, *Against the Professors* 9.115; Lactantius, *Divine Institutes* 2.5.18. See also Rawson 1985: 163 and Simms 1995: 53–55. In late antiquity: Claudian, *Epigrams* 51.68; Macrobius, Commentary on the Dream of Scipio 2.15; Martianus Capella, The Marriage *of Philology and Mercury* 8.815; Julius Firmicus Maternus, *Eight Books of Astrology* 1.pr.5 and 6.30.26. On the most advanced armillary spheres in antiquity: Ptolemy, *Almagest* 1.6, 5.1, 13.2. See also Nicolaus Copernicus, *De Revolutionibus* 2.14. It is not known what the "Billarus Sphere" captured in Sinope by Lucullus in the early 1st century B.C. was or when it was made (Strabo, *Geography* 12.3.11; *EANS* 192), but it probably would not have been singled out as remarkable unless it was some kind of armillary sphere.

432. On this now-famous Antikythera mechanism see Marchant 2010 (for a popular account) and (for expert analysis) A. Jones 2016 and 2017, Sticks 2014, and Hannah 2009: 59–67. Additional specialist literature: Edmunds 2011; M.T. Wright 2007; Freeth et al. 2006; Freeth 2002a and 2002b; Economou 2000.

433. Dobson 1918: 189–90.

434. Assessment: *OCD* 1196 (in s.v. "Posidonius (2)").

435. Sosigenes: Rawson 1985: 112–13, *EANS* 752, and *OCD* 1385, with Feeney 2007 and Pliny the Elder, *Natural History* 2.6.39 and 18.57.211–212.

436. Asclepiodotus is known for an extant (and rather sophisticated) treatise in military tactics (*OCD* 180; *EANS* 172). His lost work on natural causes provided scientific material on earthquakes and volcanoes for Seneca's *Natural Questions* (cf. 2.26.6, 2.30.1, 5.15.1, 6.17.3, 6.21.2; and discussion in Kidd 1988: 30–33), although it may have treated other subjects, and there is no telling what else he wrote books on—we are lucky even to know of these. On Athenodorus see Strabo, *Geography* 1.1.12; with *OCD* 195, and *EANS* 179.

437. *OCD* 1352 (s.v. "Serapion (2)"); *EANS* 733 (s.v. "Serapion of Antioch"). Hipparchus also wrote such a critique, and Cicero had read all three (Eratosthenes, Hipparchus, and Serapion: Cicero, *Letters to Atticus* 2.6.1). Serapion's size of the sun was a sixth of the correct value.

438. Artemidorus: *EANS* 165. For the others, see previous discussions and references.

439. Strabo: *DSB* 13.83–86, *EANS* 763–64, and *OCD* 1404–05. Theophrastus began this research (see section 3.5) and Strabo confirms it was continued by others like Eratosthenes and Posidonius.

440. Geminus: Of these, only the *Introduction to Astronomy* survives. See *DSB* 5.344–47, *EANS* 344–45, *OCD* 607, and most importantly: Evans & Berggren 2006. On dating Geminus see note in chapter 2.7. We also have some less technical astronomical textbooks from (or shortly before) the 2nd century A.D. Besides Cleomedes (see note below) we have similar textbooks from Hyginus (*OCD* 714, first or third entry; *EANS* 454), Theon (*OCD* 1460, second entry; EANS 796), and Achilles (*OCD* 7–8, first or second entry; *EANS* 51–52).

441. On Menelaus: *DSB* 9.296–302 and 15.420–21, *EANS* 546, and *OCD* 932 (s.v. "Menelaus (3)") as well as *OCD* 1507 (s.v. "trigonometry") and Russo 2003: 52–55 and Van Brummelen 2009. Menelaus also wrote a handbook on geometry, and probably others unknown to us. A papyrus fragment of Menelaus' work on astronomical theory probably survives (cf. A. Jones 1999).

442. *DSB* 15.209 (in s.v. "Hipparchus").

443. Theodosius: See Evans & Berggren 2006: 7 (and references on Theodosius cited earlier). In turn, Autolycus and Euclid wrote treatises on spherical geometry that Theodosius improved upon.

444. Plutarch, *On the Face that Appears in the Orb of the Moon* 17 (= *Moralia* 930a).

445. On Marinus of Tyre see Batty 2002, Berggren & Jones 2000: 23–25, Dilke 1985: 72–75; and *NDSB* 5.27 and *EANS* 533.

446. See Appendix A for a brief history of ancient exploration.

447. Claudius Ptolemaeus: For the following: *DSB* 11.186–206; *NDSB* 6.173–78; *EANS* 706–09; *OCD* 1236–38 (s.v. "Ptolemy (4)"); A.M. Smith 1996: 1–5; Riley 1995; Lloyd 1973: 113–35.

448. The only missing element was the ellipse (and the heliocenter), which may have been avoided for more practical reasons than is usually claimed (including the need to simplify calculation and build computer models of the solar system in the form of armillary spheres): Russo 2003: 89–93.

449. Toomer quote: *DSB* 11.196 (in s.v. "Ptolemy").

450. Well discussed in Berggren & Jones 2000 and A. Jones 2012. Though Ptolemy ultimately preferred the lower (and less accurate) value for the circumference of the earth (which ultimately derives from Posidonius—rather than Eratosthenes, whose value Ptolemy appears to have relied on in his earlier *Almagest*), he explicitly argues that this value needed revision through more accurate observations (which was true even for Eratosthenes' measurement) and thus should be accepted only provisionally (hence criticism of Ptolemy on this point, e.g. Russo 2003: 69–70, 273–77, is often unjustly excessive). And yet this value would not be improved upon until Muslim scientists followed Ptolemy's advice in the 9th century (M.J. Lewis 2001b: 156).

451. That Ptolemy actually made maps and globes and had considerable skill and experience with this is shown in Berggren & Jones 2000: 46–48.

452. Quote and other details: *DSB* 11.200 (in s.v. "Ptolemy").

453. See, for example, Ptolemy, *Almagest* 9.2.

454. Ptolemy also discusses the optical illusion created by horizon observations in *Planetary Hypotheses* 1.2.7. See Goldstein 1967: 5, 9 (with *OCD* 190, in s.v. "astronomy"), Lloyd 1982: 134–35, and A.M. Smith 1996: 2–3. Ptolemy first assumed it was an enlargement caused by atmospheric refraction, a phenomenon studied by Posidonius and later by Ptolemy himself (see related notes above and below; note this also means they knew refracting lenses could achieve magnification). More examples of Ptolemy revising his own theories in light of new evidence are surveyed in Lloyd 1982: 139–40 and Hamilton et al. 1987: 57 and 68.

455. Quote from G.J. Toomer and other points in this paragraph: *OCD* 190 (in s.v. "astronomy"). Quote from G.E.R. Lloyd: Lloyd 1981: 279.

456. See *DSB* 13.325–26 (s.v. "Theon of Smyrna") and 11.187 (in s.v. "Ptolemy"), *EANS* 793 and 796, and *OCD* 1460 (s.v. "Theon (2)"). See also Evans 1999: 296–97. (That these two Theons were the same man is not certain; but their dates and interests do align.)

457. Cleomedes: *OCD* 331, expanded and corrected by *DSB* 3.318–20 and Bowen & Todd 2004: 1–4. Though his date has long been uncertain, the most recent and careful analyses place him somewhere between the 1st century B.C. and the early 2nd century A.D. Later dates have been suggested but are very improbable. A basic astronomical textbook aimed at laypeople is his only extant work (various titles are given but *On the Heavens* is most credible).

458. *OCD* 1385 (s.v. "Sosigenes (2)"); *EANS* 753. His extensive treatise on vision is mentioned in Alexander of Aphrodisias, *Commentary on Aristotle's Meteorology* 143.13. For a fragment of his astronomical work see Cohen & Drabkin 1948: 103–05.

459. Toomer 1985: 203–04. For Apollinarius: *OCD* 118; *NDSB* 1.82–83; *EANS* 105.

460. Ptolemy, *Almagest* 7.3; *EANS* 47. A. Jones 1999 discusses Agrippa and other 1st century astronomers.

461. More going on: Plutarch, *On the Face that Appears in the Orb of the Moon* 1–23 (= *Moralia* 920b-937c). See Russo 2003: 286–93, though he sometimes goes beyond what the evidence actually supports.

Section 3.4 Scientific Physics up to the Roman Era

462. For general context and scholarship see Lloyd 1973: 91–112, Schürmann 1991: 33–59 and 2005, Vitrac 2009, and *OCD* 8–9, 291, 714, 917–18, 975–84, 1042, 1145–48, 1166–67, 1396 (s.v. "acoustics," "catoptrics," "hydrostatics," "mechanics," "music" esp. §5, "optics," "physics," "pneumatics," "statics"). Scenography (the science of visual representation in the arts) and other practical applications were a formal part of optics, e.g. Camerota 2002; Russo 2003: 58–65; Evans & Berggren 2006: 45–46, 244, 248. For the connection between ancient acoustics and ancient music: Landels 1999: 130–47, 190–95. Ancient optics: A.M. Smith 2014: 25–129.

463. See Diels 1920: 29–31; M.J. Lewis 1997: 60–61; *EANS* 29. The papyrus here reads "*ho Abdaraxôs ho ta en Alexandreiai mêchanika suntellôn*" and includes other architects and military engineers, known and unknown.

464. I will only survey the best known. For a list of *all* known physicists and engineers in antiquity see *EANS* 993 (s.v. "architecture"), 1002–03 (s.v. "harmonics"), 1005–06 (s.v. "mechanics"), and 1012 (s.v. "optics"). For writers making advances purely in mathematics (advances which continued after Archimedes well into the Roman era, but almost all of which was not preserved; even the advances of Archimedes barely survived): *EANS* 1003–05.

465. For the following, see references cited for Strato in section 3.3.

466. According to Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 5.59–60 (the latter is cited as simply *On Inventions* in Clement, *Stromata* 1.14.61 and 1.16.77). Others were writing similar books in the 3rd century B.C., e.g. *OCD* 1136 (s.v. "Philostephanus of Cyrene"; cf. *EANS* 660) and 1144–45 (s.v. "Phylarchus"). See Rihll & Tucker

2002: 287–89. Likewise, Oleson 2004, Dunsch 2012, and Greene 1992 argue there were a lot of technical manuals like these, all now lost. 467. Papadopetrakis & Argyrakis 2010; Boutot 2012.

468. Child's game: Galen, *On the Natural Faculties* 1.7 (= Kühn 2.16–17). For examples of Hero's use of heat to cause air to expand and thus drive machinery see Hero, *Pneumatics* 1.12, 1.38–39, 2.3, 2.34–35.

469. Callistratus (*EANS* 466) was no idle philosopher but a working engineer, so his textbook on the subject would have been valuable (cf. Athenaeus the Mechanic, *On War Machines* 28.7–8, with Whitehead & Blyth 2004: 140). The Pseudo-Aristotelian *Mechanical Problems* survives in extant collections of Aristotle's works. For other engineers who may have written scientific books prior to the Roman era, see lists in Whitehead & Blyth 2004: 24–25 and Cuomo 2007: 61–62, though others are mentioned throughout *On Architecture* by Vitruvius (e.g. 1.1.17, 7.pr.14, 9.8.1–2, etc.; cf. M.J. Lewis 1997: 45–46), or in scattered sources elsewhere. Athenaeus, *On War Machines* 5.3, identifies Archytas of Tarentum (see Appendix B) and Hestiaeus of Perinthus (a pupil of Plato; *EANS* 391) as having written on mechanical theory, although nothing from them survives (see Whitehead & Blyth 2004: 68–69), unless Winter 2007 is correct that Archytas wrote the *Mechanical Problems* mistakenly attributed to Aristotle.

470. Ctesibius: For the following: *DSB* 3.491–92, *EANS* 496, and *OCD* 396, as well as Vitruvius, *On Architecture* 9.8.2–7 and 10.7–8.

471. On Hero's emulation of Strato's experimental methods, e.g. in demonstrating the corporeality of air: Papadopetrakis & Argyrakis 2010.

472. For the history of ancient artillery technology and why some devices won out and not others: Rihll 2007; Landels 2000: 99–132; DeVoto 1996; Marsden 1969 and 1971. See also D. Campbell 2011 and *OCD* 178 (s.v. "artillery") and 1364–65 (s.v. "siegecraft, Greek" and "siegecraft, Roman"). Cuomo 2007: 41–76 is also worthwhile, though she overdraws some conclusions and might err in some basic physics.

473. Biton: *OCD* 235; *EANS* 193–94. Marsden 1971: 5–6 makes a fair case that Biton wrote in the mid-3rd century B.C. rather than (as some have thought) mid-2nd century B.C.

474. Apollonius of Perga: See mention and note in section 3.3.

475. Philo of Byzantium: For the following: *DSB* 10.586–89, *EANS* 654–56, and *OCD* 1133 (s.v. "Philon (2)"). On dating and contributions of Ctesibius and Philo, see Marsden 1971: 6–9.

476. Archimedes: For the following: *DSB* 1.213–31, *NDSB* 1.85–91, *EANS* 125–28, *OCD* 141–42, and Simms 1995 and 2005. Also M.J. Lewis 1997: 37–41 (and 137 n. 86); and Russo 2003: 25–27 and 70–75, who shows how Archimedes put mechanics on a scientific footing by refuting Aristotle, an example of the actual tendency in antiquity *not* to treat Aristotle as gospel, exactly opposite the behavior of medieval Christians.

477. Simms 1995: 53–55. See also related note in section 3.3 above (under Posidonius).

478. Tertullian, *A Treatise on the Soul* 14, credits a water organ to Archimedes. Archimedes, *On the Construction of Waterclocks* appears to have survived in Arabic (cf. Hill 1976 and 1984: 230–32). That Archimedes may also have written on odometer design is only conjectured (see note in chapter 3.6.IV).

479. Syracusan artillery: Simms 1995: 60–71. Discussed in chapter 4.6.I.

480. On palimpsests (documents that were erased and written over but then forensically recovered with modern technology) see *OCD* 1069 (s.v. "palimpsest") and examples to follow (Ptolemy's *Analemma*; and in section 3.8.IV, Archimedes' *On the Method of Mechanical Theorems*).

481. Archimedes, *On the Method of Mechanical Theorems*, pr. (addressed to *Eratosthenes).*

482. Apellis: *EANS* 103.

483. Hermogenes: *OCD* 670–71; *EANS* 379.

484. Agesistratus: *EANS* 45; the works of Agesistratus were consulted by Vitruvius and his much less competent contemporary, Athenaeus the Mechanic (author of an extant *On War Machines*, cf. *EANS* 176 and *OCD* 195): cf. Marsden 1971: 4–5 and Whitehead & Blyth 2004: 172–74. That Athenaeus was pretty much a hack pretending to engineering ability is convincingly argued in Whitehead & Blyth 2004: 34–39, 187-92. I therefore do not include him beyond this note, although his book attests to the achievements of his sources.

485. Posidonius: See mention and note in section 3.3 above.

486. Apollonius of Athens: *EANS* 113. See Whitehead & Blyth 2004: 18, 26, 47, 137–38.

487. Andronicus: *EANS* 81. See my later discussion of the Tower of the Winds, and sources cited there.

488. Carpus: *EANS* 468.

489. Ptolemaïs: See quote in chapter 2.7, and discussion in section 3.7; with Levin 2009: 230–93; Plant 2004: 87–89; Irby-Massie & Keyser 2002: 344–45; Barker 1989: 239–42; *OCD* 1234, *NDSB* 6.172–73, and *EANS* 705–06.

490. Heraclides: *EANS* 369–70.

491. Hero of Alexandria: For the following see *DSB* 6.310–15, *EANS* 384–87, and *OCD* 676–77; cf. also Keyser 1988 and Russo 2003: 130–37.

492. Tybjerg 2004: 34–35. The whole of Tybjerg 2004 establishes her point.

493. In addition to the analysis of Tybjerg 2004 see that of Tybjerg 2003 and Cuomo 2002.

494. Indeed, machinery for temple marvels were so standard that it was simply assumed any new temple built under the empire would be so equipped: Cassius Dio, *Roman History* 69.4.1–5.

495. Value of robots: See, for example, the analysis of automata in Schürmann 2002 and Schneider 1992: 201–07. For a different perspective, note how Russo 2003: 140–41 compares Hero's automatic theatre with a related modern invention: the cinema. Though Hero's theatrical scenes could not have moved that quickly (despite Russo's effort to argue they did), the function and value is similar.

496. Hero, *On Constructing Automata* 1.1.1 (cf. Murphy 1995: 11). On Hero's elevated and quite serious appreciation and use of mechanical marvels see Tybjerg 2003.

497. See, for example, Russo 2003: 75–78 and Landels 2000: 192–93. Tybjerg 2003 demonstrates how the ancient idea of 'wonder' (which Hero embraced and employed) included scientific demonstration of counter-intuitive principles (often with a mechanical apparatus). Hero, *Pneumatics* 2.11 describes his steam turbine, which combines rotary motion with a previous scientific demonstration device known to Vitruvius, *On Architecture* 1.6.2, which dates back to Philo, *Pneumatics* 57, and is related to another device in Hero's collection: a steam levitator (Hero, *Pneumatics* 2.6). That Hero's steam turbine was a scientific demonstration device, evolved from previous devices of the same general purpose, and deployed to challenge Aristotelian physics, is convincingly argued in Keyser 1992.

498. Tybjerg 2004: 50–51. The five basic machines are (still) the wheel, lever, wedge/ramp, pulley, and screw. Though the gear was also developed, which made six in all, this was rightly considered a combination of lever and wheel (as I'll discuss later).

499. His robotic doors (Hero, *Pneumatics* 1.38–39) were not steam powered (as I have cited some claiming in the past) but pneumo-hydraulic, and operated on a small-scale replica (not an actual temple), although such building of models often preceded full scale implementation (see Di Pasquale 2002). And though Hero's vending machine was based on earlier water-dispensing technologies (Philo, *Pneumatics* 28–34), the idea of dropped-coin activators first appears in Hero, *Pneumatics* 1.21 (cf. James & Thorpe 1994: 128–29). On the development of ancient odometers see M.J. Lewis 2001b: 134–42, 329–31 (and the note below on mechanized carriages).

500. Tybjerg 2004: 40–48.

501. On Hero's principle of least action, anticipating but not yet developing the modern equivalent, see A.M. Smith 1999: 81 (cf. also 134, and 145 nn. 9 and 10) and Boutot 2012. On Hero's *Mechanics* and *Baroulkos* see Vitrac 2009 and Drachmann 1963: 19–140.

502. *DSB* 7.29 (in s.v. "Isidorus of Miletus").

503. Hero's 'handgun', which became standard equipment in the Roman legions, incorporated numerous significant advances on previous catapult design. See Marsden 1971: 206–33 and Landels 2000: 99–132. The historical development of waterclocks is hard to track, but by Hero's time they had become quite sophisticated: Russo 2003: 101–05; M.J. Lewis 2000; Evans 1999: 251–56. Doctors even had special adjustable pulse-timing clocks (originating with Herophilus): Russo 2003: 145–46 and von Staden 1996: 89.

504. Menelaus: See references in section 3.3.

505. Ptolemy: See references in section 3.3.

506. Also missing are Ptolemy's works in geometry—one in which he claimed to have proved Euclid's parallel postulate, another (*On Dimension*) in which he claimed to have proved there can only be three dimensions, and another (*On the Elements*), which appears to have been a more comprehensive treatise in geometry in relation to theories of matter. An excerpt from Ptolemy's *On Balances*, with discussion of a problematic experiment it contained, survives in Simplicius, *Commentary on Aristotle's 'On the Heavens'* 4.4.710–11 (cf. translation and note in Cohen & Drabkin 1948: 247–48). According to the *Suda* (a 10th century Byzantine encyclopedia) Ptolemy even wrote a whole three volume *Mechanics*.

507. Though they might also have contained some erroneous theories and conclusions (just as his other works do), at least judging from the one reference to Ptolemy's *On Balances* in Simplicius (see previous note).

508. In the *Almagest* this includes construction and use of an armillary sphere in book 5, as well as a meridian ring and plinth (1.12), a parallactometer (5.12), a specialized diopter (5.14), and a practical star globe (1.22–23, 7.6–8, 8.2–3), just to name a few. Several other instruments are described in the *Optics* and *Harmonics*, and even in the *Geography* (e.g. 1.22). On these see A.M. Smith 1996, 1999, and 2014: 25–129 (*Optics*), Solomon 2000 (*Harmonics*), Berggren & Jones 2000 (*Geography*), Toomer 1984 (*Almagest*), and in general Lloyd 1982: 136–44 and Evans 1999.

509. Astrolabes: *DSB* 15.519 (in s.v. "Vitruvius Pollio"). See discussion and sources in section 3.3.

510. Ptolemy on armillary spheres: *DSB* 15.219 (in s.v. "Hipparchus"). See discussion and sources in section 3.3.

511. On Ptolemy's meteoroscope see Ptolemy, *Geography* 1.3 with Evans & Berggren 2006: 48 and Berggren & Jones 2000: 61 n. 12.

512. Sectional map: *DSB* 10.300 (in s.v. "Pappus of Alexandria").

513. Ptolemy proposes his principle of least action at the end of the surviving fragment of *Optics* 5 (see Cohen & Drabkin 1948: 281), where his discussion breaks off and is now lost. On Ptolemy's anticipation of the (now correct) theory that refraction is caused by a slowing of the rays passing through an object see A.M. Smith 1996: 42–43. On how he fell short of discovering the correct law of refraction but came close: Wilk 2004.

514. On Ptolemy's discussion of atmospheric refraction affecting astronomy see A.M. Smith 1999: 134–37 and 1996: 46, with Ptolemy, *Optics* 5.23–31. On atmospheric refraction in general, see relevant notes above, and quotations of relevant passages in Cohen & Drabkin 1948: 281–85.

515. Toomer quote: *DSB* 11.200 (in s.v. "Ptolemy").

516. Role of Didymus: *DSB* 11.200 (in s.v. "Ptolemy") citing Porphyry, *Commentary on the Harmonics* 5. See Barker 1994: 62–73 and *OCD* 451 (s.v. "Didymus (3)"), *NDSB* 2.284–86, *EANS* 244–45. Scientific harmonics (theoretical and empirical acoustics) had already begun before Aristotle and continued since, but it is difficult to reconstruct its progress from extant sources: see *OCD* 8–9 (s.v. "acoustics"). Barker 1994 argues scientific harmonics stagnated after Aristotle and then underwent a major revival in the early Roman empire. Adding to the evidence of Ptolemy

are writers on musical scales (Alypius: *OCD* 67; *EANS* 62) and the philosophy of music (Quintilian Aristides: *OCD* 155; *EANS* 134) from the 3rd or 4th century A.D., which contain evidence Ptolemy himself wrote a similar treatise specifically on *Music*. There were other writers on harmonics during the 2nd and 3rd centuries A.D. (e.g. Cleonides: *OCD* 332; *EANS* 481) and in the 1st century A.D. (e.g. Ptolemaïs of Cyrene, discussed earlier). See Barker 1994: 54 n. 2 for a longer list of known examples.

517. Mantias: *EANS* 525.

518. Balbus: *DSB* 1.418–19, *EANS* 189, and *OCD* 222; see also *OCD* 636–37 (s.v. "*gromatici*") and B. Campbell 2000: xxxix-xlii, and the relevant sections of Cuomo 2001. There were other engineers who wrote on surveying and military camp construction and other subjects in the same era, about whom we know even less (e.g. Hyginus: *OCD* 714–15, second or fourth entry, and *EANS* 426–28; Marcus Iunius Nipsus: *OCD* 766, *EANS* 457; and Siculus Flaccus: *OCD* 1363, *EANS* 740; cf. also B. Campbell 2000: xxxv-xxxix).

519. Frontinus: *OCD* 762–63 and *EANS* 453, with Rodgers 2004: 1–20. Two of his treatises survive (*On the Aqueducts of Rome* and *Stratagems*), though his more detailed *Art of War* does not, and his works on surveying survive only in fragments (see B. Campbell 2000: xxvii-xxxi).

520. *OCD* 120 (s.v. "Apollodorus (7)") and *EANS* 107–08, with Cuomo 2007: 131–32 and La Regina 1999. We know this Apollodorus designed and built Trajan's famous bridge across the Danube (Serban 2009). Architects and engineers are relatively poorly represented in the sources (*OCD* 142–44, s.v. "architects" and "architecture"), yet we know about a lot of them (including far more names than I mention).

521. Dorion and Epicrates: *EANS* 275, 292.

522. Such as a 1st or 2nd century B.C. author of a work on spherical and parabolic mirrors, whose name has become corrupted beyond recognition ("Dtrums," *EANS* 278).

523. Diophantus: Derbyshire 2006: 31–42, *DSB* 4.110–19 and 15.118–22, *EANS* 267–68, and *OCD* 465, which correctly dates him "between 150 BC and AD 280," hence probably Roman-era. A good case for dating Diophantus to the 1st century A.D. is presented in Knorr 1993 and Russo 2003: 322–23 (esp. n. 230).

524. *DSB* 13.399–400 (s.v. "Thymaridas"; cf. *EANS* 808–09). See also the debate on the status of pre-Diophantean algebra between Unguru 1975 and 1979 and van der Waerden 1976 and Freudenthal 1977; discussed in Fried & Unguru 2001.

Section 3.5 Other Sciences

525. P. Green 1990: 457.

526. Empirical study of magnetism and chemistry was not neglected, it just did not rise to the highest status of 'science' the way astronomy, physiology, or mechanics did. Ancient theories and discussions of magnetism are surveyed in Lindsay 1974: 245–72 (with examples in Cohen & Drabkin 1948: 310–14). Though no books on the subject have been preserved, we know some existed (e.g. see Theophrastus, *On Stones* 28). For an example of the state of 'theoretical' chemistry under the Romans see Alexander of Aphrodisias, *On Blending and Growth* (with commentary in Todd 1976). For discussions of practical and empirical chemistry in antiquity: Martelli 2011, Russo 2003: 165–70, Wilson 2002, Healy 1999: 115–41, Cohen & Drabkin 1948: 352–73. For a selection of literary evidence for a wide array of ancient chemical technologies see Humphrey et al. 1998: 205–34, 354–78, 880–90. The degree of scientific chemistry in the practice of alchemy in antiquity can be gleaned from the extant 3rd century writings of Zosimus (*NDSB* 7.405–08; *EANS* 852–53); and *OCD* 51–52 (s.v. "alchemy"). See *EANS* 992–93 for a list of ancient alchemical writers.

527. Even at best, magnetism was only rarely employed to produce public tricks in temple displays (cf. Pliny the Elder, *Natural History* 34.42.148 and Claudian, *The Magnet = Minor Poems* 29, with discussion in Schürmann 1991: 234).

528. Gilbert: See brief discussion and notes in chapter 1.1.

529. Theophrastus: For the following: Lloyd 1973: 8–15; Rihll 1999: 106–18; *DSB* 13.328–34 (s.v. "Theophrastus"; cf. *EANS* 798–801 and *OCD* 1461) and 245–46 (s.v. "botany"). Theophrastus also wrote numerous zoological and other works that were not preserved (and his *Meteorology* survives only in Arabic: Taub 2003: 115–24), and a few that survive only in mangled or abridged versions (e.g. *On Weather Signs*, cf. Sider & Brunschön 2007). The philosophical function and context of his more scientific work is discussed in French 1994: 83–113. But the premiere authority on all things Theophrastean is now Fortenbaugh et al. 1992–2007.

530. Russo 2003: 165–66, 210–12.

531. See Mayor 2011a (index). The whole of Mayor 2011a documents a lot of interest in this subject spanning antiquity. Though no one's books on it were preserved, we know such study influenced ancient geological theories: Russo 2003: 161–63 (e.g. Strabo, *Geography* 1.3.4).

532. McDiarmid quote: *DSB* 13.333 (in s.v. "Theophrastus").

533. See *OCD* 87–90 and 483 (s.v. "animals, knowledge about" and "ecology (Greek and Roman)"). Clearchus, another of Aristotle's pupils, also wrote lost works on zoology and mathematics (*OCD* 329–30, s.v. "Clearchus (3)"; cf. *EANS* 477), and Phanias did the same on botany (*EANS* 641; see note in chapter 2.5). At some point in the 2nd century B.C. a certain Damigeron also studied and wrote on mineralogy, and large fragments of his work *On Stones* survive (*EANS* 225; cf. *DSB* 4.121, in s.v. "Dioscorides"), but he did not quite rise to the standard of Theophrastus. We also know someone named Democritus wrote on magnets and other stones sometime in the last three centuries B.C. (*EANS* 236). Lennox 1994 discusses the vanishing interest in this theoretical zoology and botany championed by Aristotle and his pupils, and advances several fanciful theories relating to this, but he ignores or hastily dismisses most of the Roman evidence I am about to present.

534. Although we shouldn't sleight the practical sciences; e.g. that king Ptolemy's physician Apollodorus (*EANS* 105 and 106) was writing scientific treatises on wine, perfumes, and poisons and their antidotes, is still a significant continuance of scientific work.

535. *OCD* 957 (s.v. "mineralogy"). See also *OCD* 938–39 and 957–58 (s.v. "metallurgy" and "mines and mining").

536. Nicolaus of Damascus: *DSB* 10.111–12, *EANS* 577–78, and *OCD* 1014; see also *DSB* 1.268 (in s.v. "Aristotle") and Gottschalk 1987: 1122–23. We know he wrote a great deal more, including histories, ethnographies, several widely respected commentaries on Aristotle, and works in many other genres (including an autobiography), none of which was preserved. Even the extant Greek text of *On Plants* that had long been attributed to Aristotle (and is still included in some collections of his works) is a Renaissance back-translation into Greek of a Latin translation from an Arabic translation of a Syriac translation of Nicolaus' original Greek, an absurdity typical of the middle ages.
537. *EANS* 594.

538. Antonius Castor: *OCD* 112 and *EANS* 100 (maybe the same as Antonius Rootcutter: *EANS* 101); Pliny the Elder, *Natural History* 25.5.9 (with quotations or paraphrases in 20.66, 20.89, 20.98, 23.83, 26.33, etc.).

539. On Figulus see Rawson 1985: 94–95, 180–83, 288, 291–92, Griffin 1994: 707–10, Horsfall 1979: 81; with *OCD* 1016 and *EANS* 572–73. Whatever research he published has not survived, so its merit cannot be assessed. Cicero's praise of him appears in the fragmentary preface to his translation of the *Timaeus*. On Fabianus see Capitani 1991: 98–101 and Griffin 1976: 37–42.

540. *OCD* 1071 (s.v. "Pamphilus (2)") and *EANS* 606. Although Galen complained that he included digressions on local Egyptian magic (Galen, *On the Combinations and Effects of Simple Drugs* 6.pr = Kühn 11.792–98), it is unclear whether this was merely literary digression or a real defect. Pamphilus also wrote a *Physics* and a comprehensive dictionary of the Greek language, neither preserved.

541. Apion of Oasis: *EANS* 104.

542. Including Sextius Niger (*EANS* 738–39), Julius Bassus (*EANS* 451), Gaius Valgius (*EANS* 822–23), Niceratus (*EANS* 575–76), Petronius Musa (*EANS* 639), Diodotus, etc., although still of varying scientific merit (cf. *OCD* 245–46, s.v. "botany"). Pliny the Elder names several other Roman-era botanical writers otherwise unknown (20.100, 20.109,

23.83, 24.120, 25.3, 25.110, 26.93, 27.120, etc.). Healy 1999 surveys the botanical, zoological, mineralogical and other data accumulated in Pliny's *Natural History* and finds that a great deal more knowledge was available to him than could have been derived from the era of Theophrastus, which entails a lot more had been written in the interim that we have simply lost, a conclusion supported by Hardy & Totelin 2016 and the diverse contributions in French & Greenaway 1986. On the nascence of anthropology in antiquity: G. Campbell 2006; Sassi 2001.

543. We know Posidonius made good first-hand observations of the properties of bitumen, naphtha, petroleum, pumice, and asphalt, and was possibly the first to do so in such detail: Kidd 1988: 826–36, 951–53. He was also a renowned authority on volcanology and appears to have initiated the field as an observational science: Kidd 1988: 809–16, 824–26.

544. Trogus: *OCD* 1181, *EANS* 685. Trebius & Lucullus: *OCD* 1503, *EANS* 815. For examples: Pliny the Elder, *Natural History* 9.41.80, 9.48.89–93, 10.20.40–41, 32.6.15 for Trebius; and 10.51.101, 11.94.229, 17.9.58, 31.47.131 for Trogus. Both Trogus and Trebius mixed in apocryphal and legendary material, but Pliny reveals enough explicit references to occasions of careful observation to suggest their work was not frivolous. Even Aristotle and Theophrastus were not immune to the flawed and fanciful, so without these Roman books we cannot assess their overall scientific quality. But they still demonstrate a renewed interest in the subject. Similar interest (in both the scientific and the fantastic) is shown by the lost but oft-quoted books on animals and plants by Alexander of Myndus, written in the early 1st century A.D., who appears to have been a lay compiler of others' work and not an original researcher: cf. *DSB* 1.120–21, *EANS* 57, and Irby-Massie & Keyser 2002: 271–72. The same can be said of Aelian, a late 2nd or early 3rd century compiler of animal lore: cf. *EANS* 32–34 and *OCD* 18.

545. Apuleius, *Apology* 29; Servius, *Commentary on the* Georgics *of Virgil* 2.126. *See OCD 127–28, EANS 119–20, and S.J. Harrison 2000: 29–32, 65–69. Apuleius made astronomical observations to verify theories: Florida 18.32. He also shows empirical interest in medicine and pharmacology: Apology 40, 41, 48; in the anatomy and physiology of fish: Apology 38; and in the scientific study of the laws of reflection: Apology 16. He also translated into Latin some Platonic works in math and philosophy, though whether extant translations are his is disputed.*

546. Kellaway 1946: 120; *OCD* 1041; *EANS* 593–94 (not to be confused with the Oppian who wrote *On Hunting*: *EANS* 594). Oppian was certainly not writing an original scientific treatise, hence he must have had access to advanced zoological works now unknown to us. Since his descriptions suggest discoveries and observations apparently unknown before his time, he probably had at hand research produced within a century of his own writing. It is worth noting that around the same time the musician Mesomedes (*OCD* 936) was writing lyrics on sundials and glassmaking, and versifications of scientific astronomy, geography, zoology, and mineralogy were also known from this time (see discussion and notes on Aratus, Dionysius, and scientific poetry in general, in Carrier 2016: 49–51).

547. Metrodorus and Leonidas: *EANS* 554 & 503.

548. Demostratus: *EANS* 228. See discussion at the end of chapter 4.5. All his works are now lost, though scattered quotations survive (e.g. his *On Fishing* is quoted or cited in Aelian, *On the Characteristics of Animals* 13.21, 15.4, 15.9, 15.19; his On Rivers is quoted in Pseudo-Plutarch, *On Rivers* 13; he is cited on mineralogy in Pliny the Elder, *Natural History* 37.11.34; etc.). Collectively citations of him indicate a 1st century Roman official of significant status, although Pliny lists him among his 'foreign' sources (*externis*) in 1.37c (possibly because he wrote in Greek or was a native of Greece; he certainly employed Roman sources, e.g. Pliny the Elder, *Natural History* 37.23.85–86).

549. Pliny the Elder: *EANS* 671–72; *NDSB* 6.116–21. This is often disguised by hyperbolic claims about the nature and quality of Theophrastus' minor works. Hence Stahl 1962 (and 1971) unjustly disparages the scientific content of Pliny's *Natural History* (as if comparable errors were never heard even from the greatest of ancient scientists), but a sober corrective is provided by Healy 1999, French 1994, Beagon 1992, and French & Greenaway 1986, who find Pliny more reliable than has been assumed. See also the brief account of his faults and virtues (and legitimate excuses) in Lloyd 1983: 135–49.

550. On Galen's completed and planned studies on animals see discussion in section 3.2 above. Galen mentions and describes his lost book on plant physiology in *On My Own Opinions* 3.5–6. Nutton incorrectly interprets this as a reference to his (extant) *On the Natural Faculties* (Nutton 1999: 148, §P.62,4): the latter is almost entirely devoted to human, not plant physiology, and Galen is quite clear when he says he wrote three volumes proving the

physiological faculties of *plants*; moreover, in *On My Own Opinions* 3.6 he specifically distinguishes his book on plants from *On the Natural Faculties*, so they cannot have been the same.

551. Sostratus: See references in section 3.3.

552. Lucius Calpurnius Piso: *EANS* 204.

553. Pelops: *EANS* 634.

554. *EANS* has extensive lists of the known authors and works in natural history; almost none preserved (991–92, s.v. "agriculture/agronomy"; 996–98, s.v. "biology"; 1003, s.v. "lithika"; 1011–12, s.v. "meteorology"; 1020, s.v. "veterinary medicine"). For some we don't even know the author's name: see Carrier 2016: 52.

555. Encyclopedias: The philosophical functions and context of these products of the Roman period are briefly surveyed in French 1994: 149–95 (Pliny specifically: 196–255) and discussed further here in chapter 4.3. Aspects of the decline in proto-scientific natural history from the 3rd century on are briefly surveyed in French 1994: 256–303. But French generally does not discuss any of the non-extant works in the early Roman period, even though almost all first-hand research in natural history from that period is not extant.

556. *OCD* 835 and 862 (s.v. "Licinius Sura, Lucius" and "Lucilius (2) (Iunior), Gaius"). Seneca had Lucilius investigate first-hand various natural phenomena in and near Sicily (*Moral Letters* 79); Pliny the Younger requests help from 'the most learned' Sura in explaining a strange spring in Italy, which Pliny had investigated himself first-hand (*Letters* 4.30; Pliny later requests Sura's opinion on the reality of ghosts, again including his own first-hand experiences, in *Letters* 7.27). These examples are discussed further in chapter 4.3 and 4.4. Sura's immense fame as a scholar is attested in Martial, *Epigrams* 1.49 and 7.47. Nothing he wrote survives.

557. Heat and fire: Galen, *On the Causes of Disease* (cf. Mark Grant 2000: 47–51). Magnetism: Galen, On the Natural Faculties 1.14 (= Kühn 2.45–51).

558. Mental block: For example, Vernant 1983: 288–89; P. Green 1990: 472; etc. Against these arguments see Russo 2003: 26–27 (though Russo takes his argument too far in later sections of his book) and Cuomo 2007: 3–4.

559. Role of artillery advances: Suggested in Crombie 1959: 2.141–42 and Russo 2003: 110, and defended in Lindsay 1974: 383–406 (383: "ballistical problems did not come up strongly in the ancient world on account of the relatively short distance to be covered by the missiles," cf. 383–84 and 390–93).

560. Renaissance dynamics: See discussion in Crombie 1959: 2.131–226.

561. This is obvious in Galileo's *Dialogue Concerning the Two Chief World Systems*, which articulated his dynamic and ballistic theories in 1638, following a trend he had already begun by attempting to use his own (incorrect) tidal theory to prove heliocentrism in his 1616 treatise *On the Tides* (cf. e.g. Naylor 2007).

562. Except possibly one: a sequence of two passages in the Arabic translation of Hero's mechanics appears to repeat obsolete Aristotelian dynamics (in Hero, *Mechanics* 2.33, part of a Q&A section where he appears to answer two questions about differential speed of fall), but their translation into Arabic may have been compromised (if Hero was originally writing of impact force and not time of fall, a problem already noted in interpreting passages from Strato); or their inclusion could be a Muslim interpolation and not in the original Greek (Q&A sections in ancient texts sometimes became expanded by later editors); and even if genuine and correctly translated, that Hero was repeating obsolete science does not entail all Roman physicists agreed with him (just as we have seen in the case of geocentrism and visual ray theory).

563. Static and dynamic geocentrism: Ptolemy, *Almagest* 1.5–7.

564. Ptolemy estimated the distance of the star field to be less than 20,000 earth radii (roughly 92 million miles), which happens to be almost exactly the actual distance of the sun (Ptolemy estimated solar distance to be considerably less). Heliocentrism required accepting vastly greater distances for the stars. See comments of G.J. Toomer in *OCD* 190 (§8 in s.v. "astronomy").

565. Hence B.L. van der Waerden: "in my opinion, the Greeks were quite right...to reject the hypothesis" of heliocentrism (van der Waerden 1963: 57).

566. Pagan religious objections to heliocentrism: For example: Dercyllides (cf. Theon of Smyrna, *Aspects of Mathematics Useful for Reading Plato* 3.41.200) and Cleanthes (cf. Plutarch, *On the Face that Appears in the Orb of the Moon* 6 = *Moralia* 923a), but this was not typical among the elite (on pagan hostility to atheism see the end of chapter 2.6).

567. Physical objections: On these points see related discussion and notes in section 3.3.

568. On the Epicurean theory of the sun in this regard see Lucretius, *On the Nature of Things* 1.1052–1113, 2.62–166, 2.184–332.

569. Xenarchus: *DSB* 7.134 (in s.v. "John Philoponus"). This Xenarchus was the tutor of Strabo and friend of Augustus, and thus no insignificant figure (Strabo, *Geography* 14.5.4).

570. Dynamic geocentrism: Ovid, *Fasti* 6.269–71. The same is attested in other authors: Cohen & Drabkin 1948: 105–07.

571. Heliocentrism still debated: Seneca, *Natural Questions* 7.2.3.

572. Inertial dynamics still debated: Plutarch, *On the Face that Appears in the Orb of the Moon* 6–11 (= *Moralia* 922f-926b). Sambursky 1962: 234–44 provides an apt analysis of relevant sections of this text.

573. Russo 2003: 279–80. For example, see Philo, *Pneumatics* 7 and Hero, *Pneumatics* 1.pr. Keyser 1992 even argues that Hero developed some of his pneumatic machinery specifically to refute (by demonstration) certain elements of Aristotelian dynamics.

574. We are lucky even to know this: in a treatise that survives only as fragments from an Arabic translation, Alexander of Aphrodisias (in the early 3rd century A.D.) attempted to refute Galen's criticisms (in yet another lost work) of the Aristotelian physics of motion. See: Pines 1961, Nutton 1984b, and Nutton 2013: 235 (with Simplicius, *Commentary on Aristotle's Physics* 6.10.1039.12–33). For background on this Alexander: *DSB* 1.117–20, *EANS* 54–55, and *OCD* 59 ("Alexander (14)"), with Todd 1976: 2–20 and Sharples 1987. There were other Roman commentators on Aristotle whose works are largely lost (e.g. *OCD* 14, s.v. "Adrastus (2)"; cf. *EANS* 31–32).

575. However, the evidence of these debates and witnesses (of the theories and works of Strato and Aristarchus and others) in the Roman period is still sufficient to refute Russo's already-implausible contention that proto-Newtonian models of the solar system were discovered and somehow 'lost' before the Roman era. See note on this point in section 3.3. Nevertheless, Russo does present good evidence that Aristotelian dynamics was not universally accepted (cf. Russo 2003: 293–96, 302–09).

576. On ancient visual theory see A.M. Smith 1999 and 2014: 25–129, who explains the controversies and why incorrect positions were thought convincing.

577. Galen conducted extensive mathematical and empirical studies of vision (*On the Uses of the Parts* 10.12–15 = M.T. May 1968: 490–503, with 472, esp. n. 19), as did Ptolemy in his *Optics*—though his first chapter discussing his physical theory is lost, A.M. Smith 1999 partly reconstructs it from the surviving books, and it aligns with Galen's on several but not all points. Siegel 1970: 10–126 surveys both visual models and their connections to the related experiments and theories of both Galen and Ptolemy. Lehoux 2007a analyzes the role these studies played in ancient epistemological debates.

578. Evolution, however, was as yet invisible, for lack of good chronological data on speciation; it would be centuries even after the Scientific Revolution before enough paleontological data would exist to see that evolution had occurred. Darwin then combined ancient natural selection theory with the modern observed pattern of evolution to produce his famous theory.

579. See discussion in Sedley 2007 and Russo 2003: 160–65. Descriptions of ancient theories of natural selection (presaging Darwin's) can be found in Aristotle, *Physics* 2.8.198b-199b, and Lucretius, *On the Nature of Things* 2.1150–56, 5.783–877.

Section 3.6 Technological Progress

580. Role of telescope: See discussion and notes in chapter 1.1.

581. Vernant 1983: 280–81.

582. Vernant 1983: 283, where he lists numerous inventions (and more in n. 19 on p. 297).

583. Vernant 1983: 296 n. 9. See below for sources on ancient watermills.

584. P. Green 1990: 367.

585. P. Green 1990: 467–69.

586. Ibid. Though he's wrong about the camel (P. Green 1990: 367). Camels were domesticated in Arabia and the Levant long before. And hollow bronze casting (contrary to P. Green 1990: 467): that technique actually originated in Mesopotamia millennia before its appearance among the Greeks (Dalley & Oleson 2003: 7–11).

587. For example, on the economic impact of screw press technology: Lewit 2012.

588. P. Green 1990: 474.

589. M.J. Lewis 1994, who notes the inscription in question literally says "onewheeled cart," which can only be a wheelbarrow or its functional equivalent.

590. See Renn 2002 and Marchis & Scalva 2002 on the various problems with 'arguments from silence' in the area of ancient technology. Green commits a similar boner when he claims "the astrolabe" was "restricted to pragmatic arts, such as navigation" (P. Green 1990: 457). As noted in section 3.3, Diodorus and Ptolemy both wrote treatises on the construction and astronomical use of the plane astrolabe, and Ptolemy developed a more complex armillary astrolabe, and also discusses the use of the quadrant.

591. For context see *OCD* 1435 (s.v. "technology").

592. P. Green 1990: 367 and 467–69 essentially repeats the same arguments as P. Green 1986, and in both cases he closely follows Finley 1981 and 1985: 109, 113–14, 145–47. Just as Finley is obsolete on the technological point, so are almost all who preceded him (e.g. almost every conclusion in Reece 1969 is now known to be false, as is much of Pleket 1973), and so also are many still (like Peter Green) who have not caught up with current research (a point made more generally in Greene 1990).

593. There was already a more impressive list and survey of technologies in K.D. White 1984, who includes many more inventions than I will here. But his work has been greatly multiplied and reinforced by others, e.g. Wikander 1990, Schneider 1992, Chevallier 1993, Greene 1994, and Russo 2003: 95–141, and most directly by Greene 2000, who puts together a point-by-point refutation of Finley's entire project (see also following note on ancient economics), and Simms 1995: 83–93, who effectively provides a refutation of Green's own "list" (factually and methodologically). On technological progress as a feature of the Roman world see Schneider 1992: 219–23; and a great deal more has been established in the twenty years since.

594. This is the general thrust of P. Green 1990: 366–81 and 467–79, and the context of Finley's every mention of technology. Oleson 1984: 397–408 also offers reasons for the slow pace of ancient technological progress that are just as clichéd and dubious, and not well explored.

595. For ongoing debates regarding the nature of the ancient economy see Derks 2002, Scheidel & von Reden 2002, Manning & Morris 2005, and now Scheidel et al. 2013 and Andreau 2015. I've concluded the evidence in no way

supports the Finley camp. It never did. But it certainly doesn't now. On whether or what kind of 'economic rationalism' existed in antiquity see Macve 1985, who refutes several myths about ancient economic attitudes and abilities, as do D'Arms 1981, Andreau 1999 (with Pleket 2001), Meissner 1999: 99–122, Greene 2000, Christesen 2003, Russo 2003: 243–67, and Morley 2007. A more accurate account now is represented in Temin 2006. See also *OCD* 222–23, 276–77, 391 and 899 (s.v. "banks," "capitalism," "credit" and "maritime loans") with support from: *OCD* 484–86 (s.v. "economic theory (Greek)" and "economy, Greek," "economy, Hellenistic," and "economy, Roman"); *OCD* 1490–93 (s.v. "trade, Greek," "trade, Roman," and "traders"); and *OCD* 734–35 and 1526–29 (s.v. "industry" and "urbanism"). Less informative is *OCD* 787–88 (s.v. "labour"). Much better on that topic is Temin 2004 and Brunt 1987, especially in conjunction with Manning 1987, who surveys a massive increase in the size and scale of all manner of industrial operations under the Romans; and Parker 1987, who surveys a correspondingly enormous boom in all manner of trade operations under the Romans. See also Mattingly & Aldrete 2000 (on the commercial implications of the Roman food supply) and DeLaine 2000 and 1997 (on the labor implications of the Roman building industry) and Shaw 2013 (on the role of labor in Roman agriculture). And in general: Erdkamp & Verboven 2015.

596. For sandboxes see Carrier 2016: 84; and, e.g., Seneca, *Moral Epistles* 88.39. The use of water, oil, or pitch mirrors is attested by Tertullian, *To the Nations* 2.6 and Seneca, *Natural Questions* 1.12.1 and 1.17.2–3. Anatomically correct dolls with moving joints are mentioned by Galen as the preferred method of teaching the art of bandaging, in a lost work quoted in Arabic (Lyons 1963: 101). These dolls would have been full or nearly-full scale and must have been finely crafted to mimic an actual human range of motion to teach bandaging as Galen recommends.

597. Electroshock therapy: Kellaway 1946. Though Kellaway's dating of some authors is obsolete, his citation of sources is thorough and his conclusions indisputable: the use of electroshock therapy was discovered in the reign of Tiberius, was further tested and developed by Scribonius in the reign of Claudius, and its therapeutic value was confirmed experimentally by Dioscorides and Galen.

598. Scientific textual analysis: Pfeiffer 1968.

599. Though see Mercer 1975 for an extensive discussion of the wide array of carpentry tools (and related techniques) developed by the Greeks and Romans (and you will see some specific examples in coming pages, like the Roman invention of the carpenter's plane), while Mols 1999 surveys Roman advances in carpentry techniques in the construction of furniture. K.D. White 1967b and 1975a provides a similar survey for agricultural tools. R. Taylor 2003 surveys Roman innovations in construction techniques (all throughout, but esp. pp. 44–48), and Absmeier 2015 does the same for wooden buildings; while O'Connor 1993: 44–62 surveys Roman construction tools and equipment. See also coming references on wooden machinery (cranes, waterwheels, bonesetters, pumps, harvesters, wagons, ships, presses, etc.). Similarly there is a lot to explore in the technology of Greco-Roman sculpting in ceramics, stone, and bronze (Hasaki 2012). Strong & Brown 1976 and Oleson 1986 also treat a small but representative sample of technologies employed in a wide range of Roman industries.

600. Shorthand: *OCD* 1425–26 (s.v. "tachygraphy"); James & Thorpe 1994: 510; Marrou 1964: 448–50 (= Marrou 1956: 312–13).

601. Cryptography: James & Thorpe 1994: 507–12. The carrier-pigeon: James & Thorpe 1994: 525. Optical telegraphy: James & Thorpe 1994: 531–36 (and see notes on Philo in section 3.4 above, and the discussion of telegraphy's development in Polybius, *Histories* 10.43–47).

602. *OCD* 1 (s.v. "abacus"); Turner 1951; O'Connor 1993: 61–62; Maher & Makowski 2001; Russo 2003: 43; Hermanns 2010. On place notation in Archimedes: Netz 2003 (also discussing abacus: 260–61; and the system of Apollonius: 284– 86), which is sufficient on the facts, though some of his added speculations are questionable.

603. P. Green 1990: 367. In fact there were several systems of ancient crop rotation in use, demonstrating an increasing sophistication of options: cf. K.D. White 1970: 110–24 and Pliny the Elder, *Natural History* 18.50.187.

604. Fruit: Renn 2002: 15–17.

605. Julian calendar: See Pliny the Elder, *Natural History* 18.57.211. The Julian calendar was not improved upon until the Gregorian reform of the 16th century: see *ODCC* 705 (s.v. "Gregorian Calendar").

606. Hyland 1990: 250–62 (based on Persian precedents: Humphrey et al. 1998: 425–26). Though the Imperial Post was not (officially) available to private citizens, it was still an extensive and efficiently organized postal system for rapidly and systematically transporting government mail, baggage, and personnel throughout the empire, a remarkable achievement in its own right

607. On all inventions listed in this and the following paragraph (beginning with "That is certainly not a complete list") see references provided in previous sections above where each invention is mentioned, and also lists and notes in P. Green 1990: 367, 467–69. On applications of the five 'basic' machines (plus the gear) in antiquity, Drachmann 1963 is still useful, though somewhat out of date. And there is some dispute as to whether the Greeks invented or 'reinvented' the waterscrew: cf. Dalley & Oleson 2003.

608. For the full range of ancient gearing see all the cited sources on ancient machinery, above and below (I have seen each type listed in several ancient sources and artifacts).

609. Crank: Originally debated (e.g. Drachmann 1973 vs. Simms 1995: 57, Landels 2000: 10–11, and Di Pasquale 2004: 150–64), a third century inscription now establishes its use in Roman industry (Ritti et al. 2007: 147–48), and one has even been recovered from the excavation of a 2nd century Roman sawmill (Schiøler 2009).

610. Valves: Russo 2003: 123 (with diagramatic reconstruction: 124). Hero, *Pneumatics* 1.27–28 describes the use of spindle valves.

611. Cams and camshafts are employed in many of Hero's automata—even his wind-powered organ employed a cam-driven piston (cf. M.J. Lewis 1993: 143–45 and 1997: 84–115; Hero, *Pneumatics* 1.43). There is also evidence they were used in industrial machinery (see discussions of mechanized hammers and sawmills below), and to operate cylinder block force pumps (M.J. Lewis 1997: 111–13).

612. Other inventions: Some of which survive only in medieval Arabic translations of ancient Greek treatises (cf. Schomberg 2008).

613. I will leave out entirely trivial inventions, like the bottle rocket, e.g. Archytas is said to have invented a toy jet airplane, described as a wooden dove propelled by "a current of air" from within. Though Gellius' description of how it worked is inconveniently missing due to a lacuna in the manuscript (Aulus Gellius, *Attic Nights* 10.12.8–10), he seems convinced the method he was to describe would work. Some scholars regard the story as a legend, but Gellius' confidence in the face of his own skepticism leads me to conclude it was probably an ordinary soda rocket (employing vinegar and sodium bicarbonate, which were readily available). See Berryman 2003: 354–55 (and sources there) for alternative suggestions, which I find much less plausible.

614. For parchment (and the bound codex, i.e. a proper book as distinct from a scroll): James & Thorpe 1994: 485; Reynolds & Wilson 1991: 3, 34–35; Skeat 1982; Roberts 1954.

615. Gimbal: James & Thorpe 1994: 118.

616. Universal joint: Simms 1995: 63–64; Russo 2003: 110; Grewe 2009; Athenaeus, *On Siege Engines* 35–36.

617. Butt hinge: Like the modern door hinge, with two plates attached to abutting surfaces and joined by a rotating pin: British Museum 1908: 160; Hero, *Pneumatics* 1.11.

618. Water level serving the same function as the modern bubble level: Russo 2003: 238–39; M.J. Lewis 2001b: 89–96; O'Connor 1993: 59–60; Dilke 1971: 74–76.

619. Mesolabe: A kind of slide-rule for calculating scaling functions for architects and engineers: Russo 2003: 111, Netz 2002: 213–15, Knorr 1989: 131–53, Cohen & Drabkin 1948: 62–66.

620. Anemoscope: A sophisticated combination of windvane and windrose for tracking the wind: Taub 2003: 103–07, 148–49, 178–79. Some even had mechanisms for a readout indoors, so an observer could know the wind conditions before going outside (Varro, On Agricultural Matters 3.5.17).

621. Thermoscope: Essentially the world's first thermometer: Philo of Byzantium, *Pneumatics* 7 and Hero, *Pneumatics* 2.8 (see Keyser 1992: 109–10).

622. Hydrometer: An instrument for weighing the density of liquids, described in late antiquity but invented sometime before (probably by Menelaus): Hill 1993: 61–65 and Khanikoff 1860: 40–53, with *DSB* 10.300–01 (in s.v. "Pappus of Alexandria"); and Synesius, *Letters* 15, with *DSB* 13.225 (in s.v. "Synesius of Cyrene") and *OCD* 281 (s.v. "Carmen de ponderibus et mensuris").

623. Volumetric table: A systematically constructed table of stoppered basins for measuring the volumes of dry and liquid goods for sale: Mau 1908: 88–89 = Mau 1982: 92–93 (discussing an example recovered from Pompeii).

624. Perfumer's press: A powerful wedge-block press for ultra-fine extraction of liquids: Drachmann 1963: 55–56 and Mattingly 1990.

625. Sphere lathe: A lathe for turning out balls and spheres: Strabo, *Geography* 1.3.3 and Pseudo-Aristotle, *On the Universe* 391b22 (though it was simply called a lathe, cf. *LSG* 1807, s.v. "*tornos*" §II, in these contexts a sphere-making lathe is clearly meant).

626. Iron frame-saw: Meiggs 1982: 346–49.

627. Miner's lamp: A lamp bound to the forehead of miners: according to Agatharchides as reported by Diodorus Siculus, *Historical Library* 3.12.6.

628. Mechanical pile driver: Vitruvius, *On Architecture* 3.4.2 (and something similar used to compact earth is mentioned in Columella, *On Agricultural Matters* 1.6.13), with discussion in O'Connor 1993: 50–51.

629. Acoustic resonator: Mathematically designed metal jars that enhanced theatrical music: Landels 1967.

630. Garden fountain: Using pressurized water: Schürmann 2002: 49–53.

631. Snorkel: For divers, compared to an elephant's trunk: Aristotle, *Parts of Animals* 2.16.659a8–12.

632. Diving bell: A small inverted pot for delivering a pocket of air to a diver: Pseudo-Aristotle, *Problems* 32.5.960b31–33.

633. Multihook fishing line: Bekker-Nielsen 2004: 89–90.

634. Folding pocket knife: British Museum 1908: 139 (with fig. 157).

635. Whaling harpoon: Oppian, *Fishing* 5.131–51 (discussed in Rihll 1999: 111–13).

636. Heated bath: Connolly & Dodge 1998: 34–35, 238–47.

637. Shower: James & Thorpe 1994: 460. Toilets, toilet sponge, and indoor plumbing (taken for granted in Seneca, *Moral Epistles* 100.6): Connolly & Dodge 1998: 130–33, 148–49 and Pavlovskis 1973 *passim*. For a thorough study of Roman toilet technology: Jansen et al. 2011.

638. Boom-spike: Oppian, *On Fishing* 4.535–48. Inflated bladders to buoy whaling lines: Oppian, *Fishing* 5.131–51. To buoy fishnets: Bekker-Nielsen 2002: 219. Using inflated bladders as floats (even to float rafts) was a common sight: Plutarch, *On the Face that Appears in the Orb of the Moon* 12, 15 (= Moralia 926c, 928b); Aristotle, *Physics* 4.9.217a, 8.4.255b and *On the Heavens* 4.4.311b; Pseudo-Aristotle, *Problems* 25.13.939a. For examples of rafts and pontoons exhibiting float technology in ancient art: Casson 1971: 3–4, 371–72; Munteanu 2013.

639. Screw press for fulling: As shown in a painting recovered from Pompeii: Mau 1908: 414 = Mau 1982: 395; and a physical example recovered from Herculaneum (cf. Feldhaus 1954: 120–21, w. Abb. 77).

640. Asbestos: Unmistakably in Plutarch, *On the Cessation of Oracles* 43 (= *Moralia* 434a-b), who attests that such fire-proof articles were still in common use in the Roman era.

641. On the treadwheel 'pump' (and other water-lifting machinery) see Oleson 1984 and 2000, and Landels 2000: 11–13, 58–83.

642. Advanced cranes: Conceded even by P. Green 1990: 467–68. For a good sketch of a 1st century A.D. Roman tomb relief of a large crane in use see James & Thorpe 1994: xxi (for a photograph of same: O'Connor 1993: 44 and Di Pasquale 2002: 78). Vitruvius, *On Architecture* 10.2.1–10 describes the various kinds and components of cranes up to his time, including the swivel-and-boom. More detailed and advanced discussion can be found in book 3 of Hero's *Mechanics*. Both these sources on cranes are discussed in Schürmann 1991: 146–57 and Landels 2000: 84–98.

643. Maximus of Tyre, *Orations* 13.4. Vitruvius, *On Architecture* 10.2.10 also notes the use of crane technologies in the shipping industry.

644. Heavy-beam transports: Vitruvius, *On Architecture* 10.2.11–14, with Meiggs 1982: 338–46; P. Green 1990: 467–68; Schürmann 1991: 140–43; Landels 2000: 183–85; M.J. Lewis 2001a: 14. Locking pins and loading bolts: Hero, *Mechanics* 3.5–8, with Drachmann 1963: 103–06, Rosumek 1982: 128–31, Schürmann 1991: 144–46, O'Connor 1993: 54–55, Landels 2000: 89–92.

645. Railway: Complete survey of evidence in M.J. Lewis 2001a.

646. Diolkos: MacDonald 1986; Werner 1997; M.J. Lewis 2001a: 10–15. See also Pettegrew 2011 and Humphrey et al. 1998: 417–18; and *OCD* 458 (s.v. "*diolkos*").

647. Theatrical and stage railing: Hero, *On the Construction of Automata* 1.2.2; M.J. Lewis 2001a: 9–10. Roman mine railways: Wilson 2002: 21 and M.J. Lewis 2001a: 15–17. That some roads were likely rutted intentionally (and thus were effectively railways) is argued in Landels 2000: 182–83 and Humphrey et al. 1998: 418–19.

648. See *OCD* 1501–02 (s.v. "transport, wheeled"), Burford 1960, Röring 1983, Oleson 1986: 339–54, Schneider 1992: 130–40, Landels 2000: 170–85, and Adams 2012 and 2007, esp. 65–69, 81, 199–205 (wagons) and 74–77, 203–04 (harness). See also G. Mansfeld 2013. McWhirr 1987 offers a broader perspective, tying in widespread road, harbor, canal and lighthouse construction as Roman improvements to a whole ransportation 'system'. Specialized wagons were developed for hauling special cargoes overland, like bulk liquids (Kneissl 1981 and McWhirr 1987: 662). Pivoting front axles were proposed at least as early as the 2nd century A.D. (by Athenaeus the Mechanic, *On War Machinery* 33–37) and actually in use by at least the time of Diocletian (late 3rd century A.D.) and probably earlier (Whitehead & Blyth 2004: 192 n. 19; Landels 2000: 180–81; K.D. White 1984: 133–35). Röring 1983 (and Schneider 1992: 136 & 236) surveys evidence for pivots and suspension systems from the 2nd and 3rd centuries A.D., though more primitive suspensions had seen specialized use centuries before (e.g. Diodorus Siculus, *Historical Library* 18.27.3–4). It should also be noted that in the general field of transport and traction systems much has been made of a supposed Roman failure to invent the modern harness or exploit the horseshoe (e.g. P. Green 1990: 474, and even Landels 2000: 174–79, whose remarks on the economics of animal selection, here and at pp. 13–14, are otherwise correct), however "the unsuitability of ancient harness to equines has frequently been remarked in modern times, but the most recent experiments indicate that this has been exaggerated" (*OCD* 708, s.v. "horses")—in fact, almost wholly fabricated: modern experiments have confirmed that horses are unimpaired by the ancient harness system (e.g. Spruytte 1983; Schneider 1992: 136–39). Though galling of the neck was still an occasional problem even for oxen, drivers were expected to take care to prevent it, and ancient harness was even built to help this (e.g. Pliny the Elder, *Natural History* 18.49.177; K.D. White 1967a: 644). See also Burford 1960, who dispels many other myths about ancient harness (though she still clings to some). The importance (and lack) of horseshoes has also been exaggerated (see below).

649. Rudders: Casson 1971: 221–28, Landels 2000: 139–40. On sails and masts see sources in following note. Green incorrectly thinks they only developed the lateen sail (P. Green 1990: 367). For lead-plated hulls: Russo 2003: 115–16 and Casson 1971: 195.

650. *OCD* 1359–60 (s.v. "ships" and "shipwrecks, ancient"). As today, large ships were outnumbered by smaller boats, and less likely to sink, hence the disparity in the archaeological record. On Roman ship technology in general: Casson 1971; K.D. White 1984: 210–13; Meijer 1986; Oleson 1986: 354–95; Basch 1987; Schneider 1992: 140–55; Landels 2000: 133–69 and 219–24, Russo 2003: 112–16, Polzer 2008, Whitewright 2009, and especially Davis 2009

and Harris & Iara 2011; with *OCD* 1002–03 and 1508 (s.v. "navies" and "navigation," and "trireme"). The supposed oxturned paddle boat in the anonymous 4th century treatise *On Matters of War* will be discussed in section 3.8.IV below.

651. See *OCD* 546, 685 and 967–68 (s.v. "Eudoxus (3)," "Hippalus" and "monsoon"). Though certain details are disputed, monsoon riding was definitely in existence by the time of Posidonius: Kidd 1988: 254–57; Casson 1980 and 1991; Pliny the Elder, *Natural History* 6.26.100–106.

652. Athenaeus, *The Dinnersages* 5.206d-209e (5.203c-209f describes several other exceptional superships). Giant cargo ships continued to be built for other special occasions even in the Roman era: see Duncan-Jones 1977 and Casson 1971: 183–99. On the comparable evolution of Greco-Roman warship technology see Foley & Soedel 1981.

653. Lucian, *The Ship* 5, on which see Casson 1950, 1956, 1971: 186–89 and K.D. White 1984: 212 (w. 155).

654. Industrial fishing: Bekker-Nielsen 2004: 90–93 (on nets specifically: Bekker-Nielsen 2002).

655. Architecture: See K.D. White 1984: 86–90, 206–07.

656. See *OCD* 140, 142–44, 250, 254–55 (s.v. "arches," "architecture," "bridges," "building materials"); also: Oleson 1986: 183–211, Schneider 1992: 155–70, and G.R.H. Wright 2005: 1.89–109 (Greek) and 1.110–28 (Roman). On Roman innovations in the use of metal reinforcement in their architecture: Loiseau 2012. See also sources in previous note on construction and carpentry.

657. See *OCD* 128–29, 274, 1316, 1571 (s.v. "aqueducts," "canals," "sanitation," "water supply"). See also Schneider 1992: 181–93 and Oleson 1986: 211–29. Seneca gawks at how rapidly Roman canals could be filled and emptied in *Moral Epistles* 90.15. On Roman canal technology: Peacock 2012, Wikander 2000c: 321–30 and K.D. White 1984: 110–12 (plus, more briefly, McWhirr 1987: 667 and M.J. Lewis 2001b: 167–96, 340–44).

658. Inverted siphon: See Russo 2003: 118–23, Wikander 2000c: 39–94 and 103–216, Landels 2000: 34–57, Dodge 2000, and O'Connor 1993: 150–62 (plus the whole of O'Connor 1993 pertains to advances and achievements in Roman aqueduct technology).

659. Defiance of nature: N. Smith 1976.

660. The aqueduct standards may have been invented by Vitruvius: Rowland & Howe 1999: 6 and 277, with Sextus Julius Frontinus, *On the Aqueducts of Rome* 25.1 (with 26–34). Brickstamping: *OCD* 250 (s.v. "brickstamps, Roman").

661. Mail warehouse: Pitts & St. Joseph 1985: 109–13, 289–99. Buried to hide them from the enemy when a legionary camp was abandoned in Scotland, it is of more than passing economic and industrial significance that a distant Roman military outpost could have nearly a million nails in its storerooms.

662. Bridge design: See Barow 2013 and O'Connor 1993 for complete studies (O'Connor offers comparisons with later achievements: 187–88).

663. Reservoirs: Hodge 2000; James & Thorpe 1994: 384–85; Reynolds 1983: 44.

664. Highrises: James & Thorpe 1994: 365–67. Seneca is annoyed at how common highrises had become in Moral Epistles 90.7–8.

665. Value of roads: L. White 1963: 274. In contrast see *OCD* 1282–83 (s.v. "roads") with Chevallier 1976, Schneider 1992: 171–80, O'Connor 1993: 4–34, M.J. Lewis 2001b: 217–45, 347–48, and Barow 2013.

666. Raban quoted in James & Thorpe 1994: xx. On the Caesarean harbor (described in Josephus, *Jewish War* 1.5.408–1.7.414): Hohlfelder et al. 1983. On Roman harbor technology in general: *OCD* 645 (s.v. "harbours"); Hohlfelder 1997; Schneider 1992: 178–81; Houston 1988; Oleson 1988; Rickman 1988; K.D. White 1984: 106–10; Casson 1971: 365–70.

667. Cosa facility: McCann 1987 and 2002 (quotes from latter: 30, 32; mechanized waterhouse: 35–46, with Oleson's contribution to McCann 1987: 98–128). Though they identify the facility as a tidal catchery, it may have been a tidal fish farm as described by Columella, *On Agricultural Matters* 8.17, though the function would be similar. Notably, extensive evidence of the use of glass jars for pickling and storing products was also recovered at the site. For evidence of nearly industrial-scale fishing under the Romans see Bekker-Nielsen 2004 (and all the contributions to that same volume by other authors) and Marzano 2013.

668. See *OCD* 836 (s.v. "lighthouses"); Hague & Christie 1975; Seidel 2010. Pliny the Elder, *Natural History* 36.18.83 mentions the appearance of new lighthouses, and archaeology confirms that an entire network of them was systematically constructed around the Mediterranean in the first two centuries A.D. On the lighthouse at Cosa, see previous note.

669. Russo 2003: 116–18 makes a reasonable but inconclusive case for parabolics. There is no direct evidence of their use in lighthouses, but such reflectors did exist and books were written about them, and it is hard to imagine what else they were used for (Russo adds additional evidence from accounts of the Lighthouse of Alexandria). Mechanized fog horns are implied if *Aetna* 294–96 reads *ora* rather than *hora* (the mss. disagree, but *ora* is more probable), and if a water-powered horn echoing off the shore (and associated with Triton, the son of Neptune) is indeed a foghorn. Again, it is hard to imagine what else it would be. But if the passage reads *hora*, then it refers to a water-powered horn that blows on the hour. Either way, the use of a mechanized horn as an analogy in this passage entails such a thing was common enough to be familiar to any reader.

670. See *OCD* 938–39, 957, 957–58 (s.v. "metallurgy," "mineralogy," "mines and mining") with: Wilson 2002: 17–29 and 2000: 135–42; James & Thorpe 1994: 410–11; Woods 1987; Oleson 1986: 55–100; K.D. White 1984: 122–24; Rosumek 1982; Healy 1978: 86–102; Sarton 1959: 376–79; Forbes 1950.

671. Sarton 1959: 377. We already mentioned the Roman use of railways above. Schneider 1992: 71–95 and Rosumek 1982 provide more recent surveys of evidence establishing how much progress the Romans made in nearly every aspect of the mining industry. See additional discussion in section 3.6.IV.

672. Quern etc.: P. Green 1990: 367, 467–68; Reynolds 1983: 11, 25.

673. Quote of Green: P. Green 1990: 469. For sources and discussion on Roman watermills see section IV below.

674. Hero, *Pneumatics* 1.43 (which instructs the reader to build his organ pump *platas echetô kathaper ta kaloumena anemouria*, "with plates like those things called windles"). The meaning of 'windles', i.e. *anemouria* (*anemos*, "wind" + *ouros*, "favorable or useful wind" + *-ion*, "little") is debated. M.J. Lewis 1993: 143–47 argues persuasively that *anemouria* were mechanically driven wheel-fans designed to blow air (a notable invention in its own right, for which Lewis presents evidence of regular use) and that Hero was the first to reverse their operation. Russo 2003: 125–26 argues less convincingly that they were actual windmills (cf. also Feldhaus 1954: 82–83 and Landels 2000: 26–27). Other possibilities (such as wind-powered irrigation pumps, very common still to this day) cannot be ruled out.

675. Seneca quote: Seneca, *Moral Epistles* 88.21. See also Vitruvius, *On Architecture* 10.pr.3–4 (with 5.6). Thunder machines: Hero, *On Constructing Automata* 2.20.3–4. On the rest see James & Thorpe 1994: 589–92 and Murphy 1995: 6–7.

676. Seneca, *Moral Epistles* 90.15, who mentions "spraying perfumes to a tremendous height from hidden pipes" (in Seneca, *Natural Questions* 2.9.2 these systems are described as powered by compressed air and are treated as commonplace; waterjets driven by compressed air are discussed in Hero, *Pneumatics* 1.10 and 2.2) and "a dining room with a ceiling of movable panels" that change with the courses of the meal (Suetonius, *Nero* 31 says Nero had one such ceiling installed that revolved "day and night in time with the sky," which Wikander rightly notes was probably water-powered: Wikander 2000b: 409). On revolving theatres (with both stage and audience turning about): Pliny the Elder, *Natural History* 36.24.116–120, whose description is muddled but contains enough incidental detail to confirm a real account. In the 2nd century A.D. Herodes Atticus commissioned for a religious procession a gigantic ship "that wasn't hauled by animals but moved along by machines below deck" (Philostratus, *Lives of the Sophists* 2.1.550, who reports this marvel was later parked and was still on display, as confirmed by Pausanias, *Description of Greece* 1.29.1). On the robotic snail: Polybius, *Histories* 12.13.11. Rehm 1937 plausibly argues that these used concealed human treadwheel propulsion machinery. On these and other ancient robotic vehicles see Schürmann 1991: 235–49 and M.J. Lewis 1997: 84–86 (and Wachsmann 2012). Not all were internally propelled,

some only carried robotic displays powered by the float's forward motion (e.g. Athenaeus, *The Dinnersages* 198c-200b and Appian, *Civil Wars* 2.147).

677. Athletic gates: H.A. Harris 1968; Schürmann 1991: 235–36; James & Thorpe 1994: 553; Balabanes 1999.

678. Racing chariots: Sándor 2012; Crouwel 2012.

679. Amphitheaters: Connolly & Dodge 1998: 190–208; Pliny the Elder, *Natural History* 19.6.23–24.

680. Nero's water organ: Suetonius, *Nero* 41.4 (more ambiguously: Cassius Dio, *Roman History* 63.26.4). See Keyser 1988 for a discussion of the new organ design and Nero's eagerness to introduce it at Rome.

681. Recovered organ: M.J. Lewis 1997: 71.

682. P. Green 1990: 478. On the water organ in general: Russo 2003: 228–30; Landels 1999: 202–04, 267–70; James & Thorpe 1994: 602–05; and Apel 1948. For a good example of a mosaic depiction: Connolly & Dodge 1998: 217. That gladiators sometimes fought to the sound of this organ is attested in Petronius, *Satyricon* 36.6. That it was also played in theatres is attested in *Aetna* 297–299. For the recovered pieces of an actual organ (with sketched reconstruction) see sources in Rowland & Howe 1999: 306. I have personally photographed several water organs on coins, seals, and medals on display at the British Museum. I would not be surprised if it was the most widely depicted machine in extant Roman art. Several witnesses report its sound was beautiful (Pliny the Elder, *Natural History* 9.8; Athenaeus, *The Dinnersages* 4.174a-b; Cicero, *Tusculan Disputations* 3.18.43, who also attests to the organ's use at banquets; while Seneca, *Natural Questions* 2.6.5 reports that water organs could be louder than any human-blown horn). J. May 1987 makes a persuasive case that one of Seneca's neighbors was a water-organ tuner, which certainly suggests widespread use of the instrument.

683. Fire engine: James & Thorpe 1994: 368–70; Landels 2000: 79–81; Schiøler 1980; Pliny the Younger, *Letters* 10.33–34. Hero, *Pneumatics* 1.27–28 describes their use and construction (Apollodorus of Damascus, *Siegecraft* 174.1–7 also describes their counter-incendiary use in combat). Tacitus, *Annals* 15.43 says Nero required landlords in Rome to keep subsidia reprimendis ignibus ("equipment for suppressing fires") *in propatulo* ("out in the open"), which may have included firefighting pumps. See Oleson 1984: 324–25 (and 396) on the Roman 'pump corps' organized by Augustus. The idea of using these pumps as flamethrowers was realized in the Byzantine era but already imagined in the 1st century A.D. (cf. *Aetna* 294–96).

684. Hydraulic concrete: See K.D. White 1984: 85–90, 204–05 and G.R.H. Wright 2005: 2.1.181–217. Additionally, Malinowski 1982 presents scientific evidence confirming the remarkable quality of ancient concretes and mortars and the sophistication of their employment. Courland 2011: 71–135 summarizes several Roman advances in concrete, which would not be replicated for a thousand years. Brandon et al. 2014 provides the most thorough history and study of this Roman marvel.

685. The invention of the grappling harpoon is described in Appian, *Civil Wars* 5.118–19. Improvements in catapult design have been confirmed archaeologically, and go beyond mere washer design: K.D. White 1984: 217–19 (with Whitehead & Blyth 2004: 21). These Roman developments post-date our last surviving treatises on ancient artillery, though such advances were probably mentioned in contemporary works that do not survive—yet another example of the dangers of arguing from silence in the area of technological progress in antiquity (the surviving part of Hero's *Siegecraft* only discusses the history of catapults up to the 4th century B.C.). There is likewise evidence of continuing Greek and Roman innovation in incendiary combat (well preceding the much later development of Greek Fire): see Partington 1960: 1–41 and Lindsay 1974: 368–77 (with Simms 1991, who argues the myth that Archimedes burned warships with parabolic mirrors likely arose from a more standard innovation in incendiary weaponry; although Rossi & Unich 2013 argue it arose from what was actually the invention of a steam cannon).

686. Horesehoes etc.: Hyland 1990: 131–34 and Dixon & Southern 1992: 70–74; also Schneider 1992: 139. Even though the stirrup was a significant improvement on it, the fourhorned saddle was still a major advance in riding technology. The importance of the horseshoe has been exaggerated. Many experts now conclude shoeing is unnecessary as long as the hooves are not overworn and are regularly hardened (e.g. www.healthehoof.com and www.thenakedhoof.com.au), which ancient horse care attended to (e.g. Xenophon, *On Horsemanship* 4). Though Thucydides, *Peloponnesian War* 7.27.5, is often cited as evidence of the risks of unshod cavalry, this passage actually describes an exceptional forced action that could have lamed the same proportion of even modern cavalry. The

superiority of proper hoof care to shoeing may have been recognized in antiquity, since the Romans actually had both hipposandals (similar to the modern horseboot) and nailed horseshoes, yet chose to use them sparingly. Surviving examples of the latter have been recovered from as early as the 1st century A.D. (e.g. Hyland 1990: 123–24 and 234; C. Green 1966; A.D. Fraser 1934; Ramsay 1918: 142–43). Hipposandals began earlier (possibly even pre-Roman) and are much more numerous in extant finds (see ibid. and Beckmann et al. 1846: 1.442–54). Mules were also shod (e.g. already in the 1st century B.C. Catullus mentions a mule losing its shoe in *Carmina* 17.25–26, probably a hipposandal). Roman hipposandals have also been recovered that bear cleats for ice and turf (Hyland 1990: 123–24).

687. See *OCD* 1572 (s.v. "weighing instruments," though this does not mention the more sophisticated weighing instrument developed by Menelaus, already noted earlier). Simple steelyard scales were in occasional use since Classical times, but more advanced versions first appear (and come into common use) under the Romans (cf. e.g. British Museum 1908: 152–46, with figs. 170–74; and more detailed discussion in Damerow et al. 2002, who also presents evidence that steelyards were in use before Archimedes, contrary to Simms 1995: 52).

688. Looms etc.: *OCD* 1446–47 (s.v. "textile production"); Rogers 2001; Schneider 1992: 125–28; Carroll 1985; Wild 1987. In *Moral Epistles* 90.20 Seneca says the Romans had developed a means of weaving shear garments and that a new loom for this was invented after 50 B.C., which may indicate one of the new looms just mentioned or yet another invention. It should also be noted that variety and sophistication were realized even at the level of ordinary needles and hooks for sewing and knitting (cf. e.g. British Museum 1908: 137–38, with figs. 154–56).

689. See Notis & Shugar 2003; K.D. White 1967b: 119–20; British Museum 1908: 137 (with fig. 153); and Nicolson 1891: 51–56. There is some textual but no archaeological evidence of (some form of) shears or scissors in use before Roman times, but they become archaeologically abundant under the Romans, showing design improvements over time and widespread use for many different purposes. Shears were more common than scissors. Shears are any double-bladed spring-levered version of scissors, which are any double-bladed pivot-levered cutting instrument. Analogously, both spring-levered and pivot-levered tongs (and pivoted compasses) were in use in antiquity, and shears and scissors are essentially tongs with blades instead of grips. Metal pivot-levered nut crackers are treated as commonplace in Ps.-Aristotle, *Mechanics* 22.854a-b.

690. *OCD* 784–85 (s.v. "keys and locks") with James & Thorpe 1994: 472–73 and British Museum 1908: 139–46.

691. Large nuts and bolts were employed in screw presses, and screw-cutting machinery was developed to manufacture them shortly before the Roman period (e.g. Russo 2003: 97–98, 151). But smaller-scale nuts, bolts, and screws begin to appear under the Romans. See Mercer 1975: 272–73, with photograph and discussion of a 5cm threaded metal nut recovered from a Roman military site in Germany dating to the late 2nd century A.D. (overlooked by both O'Connor, who discusses the equivalent Roman use of nails and eyebolts in O'Connor 1993: 45–46, and Deppert-Lippitz 1995, which otherwise surveys examples of ancient screws of many types and sizes). For small screws as fasteners in the 1st century A.D. see the relevant sections of Hero's *Dioptra* and sources in Burkert 1997: 40. Threaded bolts as structural elements are described in Josephus, *Jewish Antiquities* 3.3.120–21. Threaded screws were also employed as adjustable valves and stopcocks in Roman pipe systems (cf. e.g. Marchis & Scalva 2002), which were clearly designed to be turned by a wrench, which entails another Roman invention.

692. Folding height-adjustable table: G. Richter 1926: 138 (with fig. 322). Folding chairs and stools date back to Egyptian times, but became increasingly popular in the classical era, and the Romans produced some of the finest examples (cf. G. Richter 1926: 39–43, 126–27). Lampstands that could be folded into themselves and adjusted for different heights: Mau 1908: 395 (= Mau 1982: 367).

693. Seneca, *Moral Epistles* 122.8, describes (with the annoyance of an old codger) hothouses with water heaters for growing spring flowers in winter (along with orchards cultivated atop roofs and walls, which would also present both irrigation and architectural challenges). Cold frames (wheeled trolly gardens, either with transparent mica roofs or able to be parked beneath them as needed) are described in Columella, *On Agricultural Matters* 11.3.52–53 and Pliny the Elder, *Natural History* 19.23.64.

694. Seneca describes a coiled-pipe heat exchanger for heating water in Seneca, *Natural Questions* 3.22.2 (which he says is a commonplace technology available in many forms). Romans innovated in the design of heating systems in a number of ways besides: Schiebold 2010.

695. Bread kneaders: Examples were recovered from Pompeii, powered by one or two men turning a handlebar, and there is evidence they were in wide use: Mau 1908: 410–11 (with fig. 241) = Mau 1982: 391–92 (with fig. 224).

696. Carpenter's plane: Gaitzsch & Matthäus 1981a: 25–29 and 1981b, with recovered pieces and a reconstruction, demonstrating sophistication of design.

697. Cave 1977 documents what we know about developments in ancient lathe technology (and its use on wood, metal, and stone) and why our knowledge must be incomplete given abundant evidence of advanced products. Pliny the Elder, *Natural History* 36.66.193 attests to the existence of glass turning, which also requires technology not otherwise attested (evidence also in Lierke 1999), as does metal polishing: though most precision pump machinery was manufactured by lost-wax metal casting rather than lathe turning, wax models of such precision must have been turned on a lathe, and precision metal parts were polished on lathes (as reported in Vitruvius, *On Architecture* 10.7.3; and confirmed by Schiøler 1980: 24–25 and Marchis & Scalva 2002: 27–28, 32–33). To generate the necessary capabilities, Cave hypothesizes a hand-powered belt-drive, but with the widespread availability of water-turned millstones, it is hard to imagine no one would think to grind other materials against them, and adapting the same or similar machinery to a fast-turning lathe may then have become obvious.

698. Pantograph: P. Green 1990: 467; Drachmann 1963: 33–43, 159; cf. Hero, *Dioptra* 34.292, *Mechanics* 1.15, 1.18, and 2.30 (in fact the description in 1.18 appears to incorporate a lead pencil, which would be yet another noteworthy invention).

699. Hero, *Pneumatics* 2.34–35 describes two demonstration devices that used a fire to cause expanding air or steam to vent back onto the fuel, becoming a self-powered bellows. The possibility of a water-powered bellows in mining operations has been proposed (see note below), and bellows machinery may be the intended analogy in *Aetna* 555–65, e.g. "what greater engines can art move by hand" than those heating volcanic furnaces (*quae maiora...artem tormenta movere posse manu*) appears to reference a bellows operated by windlass (*tormenta*) and in some manner cleverly constructed (*artem*).

700. Rotating turrets on conical rollers: Russo 2003: 264–65.

701. This was a luxury carriage owned by Commodus and later sold at auction, according to 'Julius Capitolinus', *Life of Pertinax* 8.2–7 (one of the more trustworthy books of the *Augustan History*). M.J. Lewis 1992 argues this passage derives from lost sections of the *Roman History* of Cassius Dio (who would have been an eye witness). Lewis argues this had a seat geared to the wheel-train so it would always face away from the sun (probably north). The seat was also geared to turn into the wind, which implies an overall mechanism of considerable sophistication—even if this meant the seat could be disengaged from the directional train and swiveled manually, though the text implies both functions were automated. Lewis speculates the design went back to Archimedes, but he offers no good case for that; it is explicitly said to have been a "new" design in the reign of Commodus. The same passage also mentions other mechanical carriages among his property, including an odometer and (possibly) a traveling clock. Lewis thinks the latter is a mistake for a static clock, but his reasoning (that such a clock would have no use and would hardly function in transit) is not conclusive: a carriage-mounted clock would not have to function while moving, and would certainly be useful when encamped (even portable sundials existed at the time). Sleeswyk 1981 makes a more convincing (though still inconclusive) case that Archimedes invented the first odometers (described by Vitruvius in the 1st century B.C.), which were more primitive than the versions developed by Hero (a century later), but that would not mean all mechanized carriage equipment originates with Archimedes, or that any such equipment had not been substantially improved (like the odometer) by Roman engineers (e.g. stationary mechanical clocks and sundials even predate Archimedes, yet continued to be improved in the Roman period).

702. Cylinder-block force pump: Stein 2004, Oleson 2004, M.J. Lewis 1997: 111–13.

703. Soap: Mishnah, *Shabbat* 9.5e-f and *Niddah* 9.6; Galen, *On the Composition of Drugs According to Location* 2 (= Kühn 12.589) and *On the Therapeutic Method* 7.4 (= Kühn 10.569); and LSG 1583 (s.v. "*sapôn*"), which confirms that the use of soap is attested from the medical writings of Rufus, Asclepiades, Galen, and Aretaeus. Previously the most common detergent had been various forms of sodium carbonate (cf. *LSG* 1177, esp. s.v. "*nitron*" and "*nitroô*"). Partington 1960: 306–09 and Beckmann et al. 1846: 2.92–108 treat extensively the evidence for soap and other detergents in antiquity.

704. Shaft furnace: Frere 1987: 287–88, Healy 1978: 188–89 and Blair 1999. Blair's claim that we "know" Roman smelting facilities did not employ another more efficient convection furnace otherwise known outside the empire's borders is actually highly questionable (both methodologically and archaeologically), but neither can a Roman adoption of it be proved, so I leave it out of account.

705. Fish farming: James & Thorpe 1994: 399–404; Marzano & Brizzi 2009; Columella, *On Agricultural Matters* 8.16–17. And previous notes on Roman fish farming.

706. *OCD* 717 (s.v. "hypocaust"); James & Thorpe 1994: 424, 462–63; and for a thorough study: Lehar 2012. That large hypocaust boilers used chimneys: K.D. White 1984: 44. Hypocaust ducting passed under the floor of a house, up the walls, and out the rooftop. Commercial bakeries employed ovens with ceiling vents of similar design (Mau 1908: 273–75, 409–10 = Mau 1982: 266–67, 391), though Roman cooking usually involved ventless front-loaded wood furnaces (like those still employed in traditional pizzerias), open braziers (like modern barbecue grills), and double-boilers (another Roman invention), always in well-ventilated kitchens (*OCD* 649, s.v. "heating").

707. For this and following see *OCD* 618 (s.v. "glass"); G.R.H. Wright 2005: 2.1.279–92; E.M. Stern 1999; Fleming 1999; James & Thorpe 1994: 464–68; Schneider 1992: 108–19; P. Green 1990: 467; K.D. White 1984: 41–42; Grose 1977; and Trowbridge 1930 (esp. 95–137 on the ancient glass industry, and 138–93 on its products). For ancient discussions see Strabo, *Geography* 16.2.25 and Pliny the Elder, *Natural History* 36.66.193–67.199 (with examples in Seneca, *Moral Epistles* 9.31, 86.8, 90.25, etc.).

708. Solar heating: In addition to the sources in previous note see Trowbridge 1930: 186–90 and Ring 1996 (who demonstrates the Romans achieved large gains in fuel efficiency with window design).

709. See *OCD* 962 (s.v. "mirrors"); James & Thorpe 1994: 252; Trowbridge 1930: 184–86; Pliny the Elder, *Natural History* 33.45.130 and 36.46.193. 710. See *OCD* 791, 836 (s.v. "lamps," "lighting") and Trowbridge 1930: 190–91. The earliest extant mentions of household glass lamps begin in the 4th century A.D., when archaeology also confirms their existence (along with the expanded use of household glass in general), though the invention and use of a thing can long predate its literary or archaeological appearance. Likewise, cities had often been lit at night on special occasions (e.g. Suetonius, *Caligula* 18), but it is unknown when cities began to engage this as a regular expense, though again the earliest extant mentions of municipal streetlights begin in the 4th century. Beckmann et al. 1846: 2.172–85 is still a useful survey of attestations of occasional and municipal streetlighting in antiquity.

711. British Museum 1908: 108–10 (with fig. 114) discusses a portable bronze lantern frame recovered from Pompeii that contained a cylindrical transparent case (now lost), with evidence of transparent soapstone in other contexts. For a better photograph see Ciarallo & De Carolis 1999: 260, who propose a casing of parchment or gut. But this frame's construction looks very similar to that of a small glass menagerie described by Hero, which he recommended be cased in either glass or transparent horn (*diaphaneis êtoi hualinoi ê keratinoi*: Hero, Pneumatics 2.3). At any rate, whether using horn, soapstone, parchment, gut, or glass, the technology of transparent lantern encasement had certainly arrived by the 1st century.

712. Glass ampules for the water level: Dilke 1971: 76–79 (and discussed in Hero's *Dioptra*). Pneumatic cupping glass: Hero, *Pneumatics* 2.17 (incorporating two small bronze shaft valves). Glass instruments in alchemy: Irby-Massie 1993: 362–63; Martelli 2011.

713. Syringe: Hero, *Pneumatics* 2.18 (essentially identical to the modern syringe).

714. Diopter: Moreno Gallo 2009; Coulton 2002; James & Thorpe 1994: 417–18; P. Green 1990: 467; K.D. White 1984: 170–71. A binocular diopter had already been invented by Democlitus and Kleoxenus in the 2nd century B.C. (*EANS* 234 & 484). The Romans used many other surveying instruments, like the groma, libra, and water level, whose origin is less certain (M.J. Lewis 2012; Grewe 2009; M.J. Lewis 2001b: 109–33, 318–28; Dilke 1971: 66–70). Diopters had undergone a whole series of improvements over time, from the Classical into the Roman period, and simpler models remained in use. On the variety of ancient diopters and the history of their development see Evans & Berggren 2006: 38–42; M.J. Lewis 2001b: 36–108, 305–17; and Dilke 1971: 76–79.

715. Rings: Cuomo 2001: 151–52 and Taub 2002. Augustan dial: Pliny the Elder, *Natural History* 36.15.72–74; Beck 1994: 100–05; Cuomo 2001: 151–153; and references in Swan 2004: 280. Athenian clocktower: Vitruvius, *On*

Architecture 1.6.4 and 9.8, with *DSB* 15.518–19 (in s.v. "Vitruvius Pollio"), *OCD* 336 (s.v. "clocks"), Noble & de Solla Price 1968, Rawson 1985: 163, and Schürmann 1991: 261–70.

716. Cuomo 2001: 151–153 describes how other cities built public sundials of their own, though much less lavish in scale than the Augustan monument; likewise, Schürmann 1991: 258–72 discusses evidence of monumental waterclocks in Samos, Pergamum, Prienne, etc. A large clock face (two feet in diameter) dating from the 1st or 2nd century A.D. was excavated in Austria (cf. Noble & de Solla Price 1968: 352; and Eibner 2013), suggesting public waterclocks were not rare. Cicero knew of mechanical clocks as complex as armillary spheres (*On the Nature of the Gods* 2.38.97) and Lucian says waterclocks were expected at any decent public bath (*Hippias* or *The Bath* 8). Varro expected them even at the best country villas (*On Agricultural Matters* 3.5.17). Public anemoscopes were also commonplace instruments (see earlier note).

717. See *OCD* 895 (s.v. "maps"), Talbert 2012; Talbert & Unger 2008; and Dilke 1985.

718. See *EANS* 640 and *OCD* 1118 (s.v. "Peutinger Table") with Dilke 1985: 112–20 and Talbert 2012: 163–92. The extant Peutinger map was based on a 4th century A.D. modification of a 2nd century (or earlier) design and thus might not represent the quality of the original, but even the Peutinger is a reasonably accurate anamorphic map of roads, cities, and waystations, marked with distances, from Britain to India.

719. Agrippa's map was constructed in the Porticus Vipsaniae. Since Agrippa also wrote a geographical commentary (now lost), his map probably incorporated scientific knowledge. See *OCD* 1554–55 (s.v. "Vipsanius Agrippa, Marcus") with Dilke 1985: 39–53 (which also discusses evidence of other publicly displayed maps) and Talbert 2012: 163–92. For a survey of debate on the existence of this map see Scott 2002: 13–16 (and on the tapestry see the whole of Scott 2002).

720. See *OCD* 585 and 895 (s.v. "Forma urbis" and "maps") and Dilke 1985: 103–10 (who also discusses evidence of other municipal maps like this one in cities throughout the Roman empire).

721. Jackson quote: Jackson 1988: 113–14.

722. Healy quote: Healy 1978: 250.

723. Surgical tools: See Healy 1978: 246–51; Jackson 2010, 1995, and 1988: 92–94, 113–29; James & Thorpe 1994: 11–17, 19, 29–30; Nutton 2013: 186–88. On the cataract needle syringe specifically, one the most impressive achievements of precision craftsmanship: von Staden 2002: 43; James & Thorpe 1994: 19; Jackson 1988: 123. For a comprehensive survey of archaeologically-recovered medical instruments see Künzl 1996. For a similarly comprehensive survey of discussions and descriptions of medical instruments in ancient literature see Milne 1907. For a general study of both: Bliquez 2015.

724. Dental drill: James & Thorpe 1994: 35. This microdrill saw medical applications beyond dentistry, cf. Milne 1907: 133 (with 21, 25, 126–32).

725. Catheter: In Galen, *On Medical Experience* = Walzer 1944: 140–41 (this is an English translation from an Arabic translation of a lost Syriac translation of Galen's original Greek). See also James & Thorpe 1994: 15–16.

726. Abortion instrument: Tertullian, *On the Soul* 25. He follows by describing a simpler instrument that he says was used by older doctors, implying the more elaborate device was a relatively recent invention.

727. Kidney stone extractor: Celsus, *On Medicine* 7.26.3b.

728. And to invent (see von Staden 1998). On such medical machinery see von Staden 1989: 453, 474 and Drachmann 1973: 38–42 and 1963: 171–85 (also M.J. Lewis 1997: 54–56), as well as descriptions in: Celsus, *On Medicine* 8.20.4; Galen, Commentary on Hippocrates' 'On Joints' 1.18 and 4.47 (= Kühn 18a.338–39 and 18a.747) and Commentary on Hippocrates 'On Fractures' 2.64 (= Kühn 18b.502–06); Oribasius, *Medical Collection* 49.4.8–13, 49.4.19–20, 49.4.45–50, 49.5.1–5, 49.6; and in following note.

729. Galen, *On the Uses of the Parts* 7.14 (= M.T. May 1968: 364–66), which also describes a bonesetter and discusses the mechanical principles behind it.

730. Medical windlass: Soranus, *Gynecology* 21.68; Apollonius of Citium, *On Joints according to Hippocrates* 2 and Hippocrates, *Joints* 42–47 and 72.

731. Alchemical instruments: Martelli 2011; Wilson 2002.

732. Ice-vending industry: James & Thorpe 1994: 320–22, with: Plutarch, *On the Principle of Cold* 15 (= Moralia 951c), Questions at a Party 6.6 (= Moralia 691c-692a); Seneca, Natural *Questions* 4b.13.8–11 and *Moral Epistles* 95.21, 95.25; Pliny the Elder, *Natural History* 19.19.52–56; Galen, *On Venesection against the Erasistrateans at Rome* 3 (= Kühn 11.205) and *On the Therapeutic Method* 7.4 (= Kühn 10.467–68); and perhaps: Petronius, *Satyricon* 31; Pliny the Elder, *Natural History* 31.23.40; Suetonius, *Nero* 27.2; Pliny the Younger, *Letters* 1.15.2. Snow storage predates the Roman era, but probably not its use as a business enterprise, cf. Beckmann et al. 1846: 2.142–60 (who also reports from his own observation that the very same methods, still in use in Portugal in the late 18th century, could keep snow through a whole summer).

733. See *OCD* 791, 836 (s.v. "lamps," "lighting"); Grandjouan 1961 (on streamlining of manufacturing methods: 2–3); also W.V. Harris 1980 and Oleson 1986: 335–37 and Simms 1995: 87 (plus examples in British Museum 1908: 172–78). Mold casting was also commonly employed in the metal and glassware industries. Organized 'assembly lines' had long been in use for various industries in antiquity: Humphrey et al. 1998: 390–400. On a related note, Pliny the Elder, *Natural History* 34.6.10–11, discusses what appears to be the development of interchangeable components for bronze chandeliers, crafted separately and assembled elsewhere. On gargantuan ovens for the mass production of ceramics: see Schneider 1992: 104, 234. Efficiency in industrial-scale pitch and charcoal industries under the Romans: Orengo et al. 2013.

734. Beroea inscription: Ritti et al. 2007: 146.

735. On ore-crushing see following two notes. On simple hushing and strip mining (involving manmade reservoirs, aqueducts, and steerable piping aimed by an operator): Pliny the Elder, *Natural History* 33.21.74–75. Sawmill: Rosumek 1982: 134–38 and M.J. Lewis 1997: 114–15. Our knowledge of ancient water-powered saw mills used to be based solely on the (albeit sound) conclusions of Simms 1983 and 1985, regarding a description of an automated stone saw in Germany (near Trier) in Ausonius, *Mosella* 361–64, who wrote in the 4th century A.D. (but giving no indication of when the sawmill began operation). Though Lynn White challenged the authenticity of this poem, he is adequately rebutted by Simms; and the evidence has multiplied since. Fragments of mechanically sawed stone from the Roman period were later found on the isle of Thasos and at Trier (Ritti et al. 2007: 156; Neyses 1983: 218–21); and three Byzantine sawmills of the sort described by Ausonius were excavated, in Ephesus, Jerash, and Gerasa (all operating in the 6th century: Ritti et al. 2007: 149–53 and Seigne 2002)—probably not the first of their type, just the first ones we were lucky to find. As proved by subsequently recovering the metal crankshaft of a Roman sawmill in Switzerland dating to the 2nd century (Schiöler 2009). An inscription from the 3rd century even depicts one already operating in Hierapolis, in what is now Turkey (Ritti et al. 2007; Grewe 2010). Another inscription of the same place and century establishes a whole watermiller's guild had arisen to care for that region's waterwheel tech, entailing a substantial industry; and similar guilds are known as far back as the 2nd century (Ritti et al. 2007: 144–45, Wilson 2002: 11, M.J. Lewis 1997: 71, and Wikander 1990: 73). In the 1st century, Pliny the Elder, in *Natural History* 36.9.51–53, described the sawing procedure employed in Roman stonecutting mills, which matches the evident operation at Ephesus, Gerasa, and Hierapolis—Pliny just doesn't mention the power source (whether water, human, or animal). Two other passages in the 4th century also suggest mechanized sawmills were commonplace: Gregory of Nyssa, *Homilies on Ecclesiastes* 3.321 (= Hall 1993: 63), refers to the clever contrivances (*mêchanêmata*) by which stone is sawed "with water and iron," as if anyone would readily know what he meant, and Ammianus Marcellinus, *Deeds of the Divine Caesars* 23.4.4, assumes his readers would be more familiar with "sawing machines" (*serratoriae machinae*) than onagers (a common siege weapon at the time).

736. On ore mills: Healy 1978: 142–43 (cf. also Spain 2002: 50). Pliny the Elder, *Natural History* 36.66.194 mentions sandgrinding by pestle and millstone, and in the Roman period the latter were typically powered by animals or water. Though we have no specific evidence of watermilled ore or sand, we have no reason to expect such evidence even if it was common, yet such an application would have been as obvious and unremarkable as grinding by ox-mill. It would also have been obvious that millstones used in rotary machines could be manufactured using the very same rotary machines.

737. A fragment of Plautus (fr. 12, from the 2nd century B.C.) uses a simile involving a "Greek hammer" in the sense of a reciprocating machine, as if it were a readily known mechanism (see *OLD* 1380, s.v. "*pilum*1"). On evidence for the use of mechanized ore-crushing hammers in Roman mining operations see Wilson 2002: 21–24 and Wikander 2000b: 406–07 (who also mentions evidence of automated hammers in Roman iron works, and possibly a water-powered bellows). For evidence supporting an even wider exploitation of robotic hammers in the Roman period see Spain 1985: 121–23 and M.J. Lewis 1997: 84–115 & 123–24 (including possible use in Roman fulling mills: M.J. Lewis 1997: 89–100 and Wikander 2000b: 406; and in Roman armor manufacture: Fulford, Sim, and Doig 2004: 218–19).

738. *OCD* 955 (s.v. "mills"), plus James & Thorpe 1994: 389–92 and Landels 2000: 16–26 (there is also a "List of ancient watermills" maintained at Wikipedia, collecting examples of watermills for both grinding and sawing). On the watermiller's guilds see previous note. On ancient watermills, still useful is Reynolds 1983: 9–46, despite the fact that he makes many dubious and unwarranted generalizations from the evidence (and overlooks some as well, e.g. compare K.D. White 1984: 193–201). Together, Wikander 1990 and 2000a, M.J. Lewis 1997, Spain 1985 and 2002: 54–55, and Wilson 2002: 9–15, provide a much-needed corrective (though not without their own flaws). See also Spain 2008. But Reynolds' errors range well beyond those demonstrated by recent scholarship, e.g. Reynolds claims Vitruvius describes watermills "in a section dealing with rarely employed machinery" (Reynolds 1983: 17 and 30) and then concludes they were rarely used in the 1st century B.C., ignoring the fact that Vitruvius includes cranes and catapults in the same section, which were actually technologies in frequent use. In fact, Vitruvius does not say these were rarely *employed*, but rarely *known*, i.e. seldom encountered or understood by laypeople. Literally, things *raro veniunt ad manus*, "that seldom come to hand" (or are "seldom understood," per *OLD* 1077 §14, in s.v. "*manus*"), hence Vitruvius aims to make them *nota*, "known" or "understood" (Vitruvius, *On Architecture* 10.1.6; cranes are the first subject immediately following this remark: 10.2; watermills: 10.5; indeed, watermills come immediately after treadmill pumps, and other wheel and bucket pumps, also common technologies: 10.4; catapults and ballistae: 10.10–12). Vitruvius considers these things 'rarely encountered' only relative to "everyday things, ready to hand, like handmills, blacksmith's bellows, passenger wagons, two-wheeled carts, lathes, and other things that find general use in daily life," i.e. things the average Joe would see every day.

739. Pliny the Elder, *Natural History* 18.23.93: *maior pars Italiae nudo utitur pilo rotis etiam quas aqua verset obiter et mola*. Because this passage is obscure and believed to be corrupt, it has been creatively interpreted to mean everything from horizontal watermills to mechanical trip-hammer mills (see Reynolds 1983: 355 n. 51), despite the fact that vertical watermills are far more plausible (e.g. when Pliny wrote there was a vertical watermill in operation just outside Pompeii, not far from where Pliny lived: Reynolds 1983: 36; Roman-era turbine watermills also existed but probably post-date Pliny: Schneider 1992: 48; Wikander 2000a: 377). If the extant text is as Pliny wrote it, then *mola* is in the ablative singular, and three machines are meant (pestle, watermill, and the more common millstone turned by mules, oxen, or slaves). But if the text is corrupt, it may have originally said *et molit*, "wheels which passing water turns and [as a result] grinds [the grain]." This is even more likely if *obiter* refers not to the water chancing by but means "at the same time" or "incidentally, besides, into the bargain" (*OLD* 1213, s.v. "*obiter*"), hence "most of Italy uses the plain pestle, as well as wheels that water turns, also [turning] a millstone into the bargain," which an emendation from *mola* to *molit* (or even *molas* or *molam*) would support.

743. *OCD* 42–43 (s.v. "agricultural implements: Roman"). See also Rees 1987 and K.D. White 1967b and 1975a. K.D. White 1970 (esp. 446–54) is a bit over-pessimistic but nevertheless documents advances, while K.D. White 1984: 195–96 provides a brief list of examples of ancient progress in agricultural tools and techniques.

744. Giant scythe, hinged flail, pruning knife, and barrel: L. White 1963: 281. Though he notes these (like the most popular Roman wagon designs: White 1967b: 13 n. 3) were Celtic in origin (just as soap was German), they were still invented more or less within the Roman empire and adopted throughout. See K.D. White 1967b: 71–85, 102–03, 207–10 (development of the scythe) and 93–96 (advanced pruning knife), and 1975b (on the Roman adoption of Celtic technology in general).

745. Columella, *On Agricultural Matters* 6.19 describes the veterinary corral in detail—he calls it a *machina*, and it was more than elaborate enough to justify the label. A modification of the same mechanism to assist the mounting of mares by donkeys is then described in 6.37.10.

746. Advanced plows: Pliny the Elder, *Natural History* 18.48.172–173. Pliny says employing two or three pairs of oxen on one large plow was typical. The Romans employed a variety of other plows according to circumstances: ibid. 18.48–49.171–183. See *OCD* 1164 (s.v. "ploughing (Roman)") and K.D. White 1967b: 123–45. There is evidence

Eratosthenes had written on plough design in a lost treatise on architecture (M.J. Lewis 1997: 77); so there may have been Roman treatises on the same topic.

747. Labor saving: For example, see Pliny the Elder, *Natural History* 18.49.181 and 18.67.261.

748. Capital investment: Columella, *On Agricultural Matters* 1.1.1–2 and 1.1.18 (for examples of his recommended investments to improve the efficiency and productivity of a farm: 1.4.7–8, 1.6.4–24, 2.2.9–14).

749. Beekeeping: *OCD* 43 and 227 (s.v. "agricultural writers" and "bee-keeping"). Besides Cato, Varro, Columella, and Palladius, from whom agricultural works survive, some of the lost writers include: *OCD* 288 (s.v. "Cassius Dionysius," translated a major Carthaginian treatise on agriculture, and also wrote his own, in the early 1st century B.C.), *OCD* 1320 and 1504 (s.v. "Saserna" and "Tremelius Scrofa, Gnaeus," each wrote agricultural manuals in the early 1st century B.C.), *OCD* 714 (s.v. "Hyginus (1), Gaius Iulius," wrote *On Agriculture* and *On Bees* in the late 1st century B.C.), *OCD* 756 (s.v. "Iulius Atticus," wrote on how to reduce costs and maximize production in the wine industry in the early 1st century A.D.), *OCD* 603 (s.v. "Gargilius Martialis, Quintus," wrote on tree farming and veterinary medicine in the early 3rd century A.D.); many more agricultural and veterinary writers are listed in *EANS*. See also *OCD* 134 and 353 (s.v. "arboriculture" and "Columella, Lucius Iunius Moderatus"). The dates of Aristomachus of Soli and Philiscus of Thasos are uncertain, and their writings are lost, yet they were the most famous and diligent scientific bee researchers in antiquity, cf. Pliny the Elder, *Natural History* 11.9.19 and Russo 2003: 251 (with *EANS* 138–39 and 649). It appears that the most experimental agricultural research occurred in Ptolemaic Egypt in the 3rd century B.C. (*OCD* 123, s.v. "Apollonius (3)") and it is from that time that we hear of the first zoos, whose subsequent fate is unknown (one at Mithridates' palace in Pontus: Strabo, *Geography* 12.3.30; another at Ptolemy's palace in Alexandria: Athenaeus, *The Dinnersages* 14.654b-c).

750. Wine presses: Pliny the Elder, *Natural History* 18.74.317, on which see K.D. White 1984: 184–85. Hero, *Mechanics* 3.13–20 (cf. Drachmann 1963: 110–35) details an even wider variety of innovations in press design, and Hero, *Mechanics* 3.21 (cf. Drachmann 1963: 135–40) discusses his related screw-cutting machine. So the point holds even if Pliny has his history wrong as Russo claims—however, Russo mistakes Pliny as referring to the screw press in general rather than new versions of it (Russo 2003: 150–51).

751. Columella, *On Agricultural Matters* 4.29.15–16, describes the advantages of his new grafting auger. Pliny the Elder, *Natural History* 17.25.116, is equally impressed with it. Such experimentation was not unusual. Galen's father "carried out experiments on his crops and wines to improve their quality" according to Nutton 2013: 222, 247 (cf. e.g. Galen, *On the Powers of Foods* 1.37 = Kühn 6.552–53 = Mark Grant 2000: 107–08). And we have many epigraphic examples of engineers expressing pride at their innovation and problem solving (Kolb 2015).

752. Complaint: Seneca, *Moral Epistles* 90.21 and *Aetna* 265–70.

753. *OCD* 44–45 (s.v. "agriculture, Roman"); with Schneider 1992: 52–71, Shaw 2013, and Bowman & Wilson 2013. Lirb 1993 argues that even small-scale farmers benefitted from equipment and animal sharing cooperatives in antiquity, which would have expanded access to agricultural technologies beyond the elite.

754. Quoting Kevin Greene, *OCD* 1435 (in s.v. "technology"). See also *OCD* 128–29 (s.v. "aqueducts"), and Schneider 1992: 181–93, for some of the peculiar features of ancient technology that exceeded medieval. Scholarship on the massive decline from Roman prosperity in industry and agriculture experienced in the middle ages is collected in Carrier 2014b (reinforced by Loseby 2012 and Brun 2012).

755. Coal: Travis 2008; Frere 1987: 288; James & Thorpe 1994: 409. The less efficient fibrous lignite was already in limited use in early Italy and Greece as an industrial fuel (Theophrastus, *On Stones* 13 and 16; cf. Caley & Richards 1956: 81–82, 85–86 and Healy 1978: 149), but even less efficient charcoal remained the most common industrial fuel across the empire (Healy 1978: 150–52; Oleson 1986: 172–81). On this situation inhibiting development of steam power see Oleson 1984: 402–03, though in the end he still resorts to the 'ancient people were stupid' argument, which is quite out of place in a book he had just filled with unchallengeable evidence of their intelligence and ingenuity (which is amplified abundantly in the present chapter).

756. Quote of Green on precision tooling: P. Green 1990: 474. The quality of Roman metal tooling was indeed superb: see Schiøler 1980 and 1989.

757. To be at all attractive to an ancient investor, the wood (or other fuel) to power a steam engine must cost less per unit of work done than the food to power a man or animal at the same task, which is not easy to do, considering how little men eat, and how cheaply animals can be fed. Landels 2000: 28–33 discusses the prospects for steam power, though is over-optimistic about the relative cost of charcoal (especially in Alexandria).

758. See Hills 1989: 13–30 and Savery 1702. See also Simms 1995: 88 and Russo 2003: 126–28. Over the course of about a century before Savery's invention a variety of steam equipment had been inspired by Hero's precedents, but none of these imaginative devices ever saw industrial application (e.g. Keyser 1992: 114–17; Dickinson 1939: 4–18, 192–93; Galloway 1837: 7–15).

759. Chemical discoveries: Whose origins are most difficult to date, but for examples of what was in use see sources on practical and empirical chemistry in the related note in section 3.5.

760. Improvements vs. inventions: On this distinction in the context of Greco-Roman times see Russo 2003: 209–10. Edelstein 1952: 579–85 surveys a few examples of ancient science influencing technology.

761. Quote of Green: P. Green 1990: 363 (similarly Vernant 1983: 283: "yet this ingenuity did not transform the technology of the ancient world").

762. Subsidized medical care: See chapter eight of Carrier 2016.

763. Value of force pump: Oleson 2005: 211–31.

764. Quote of Green: P. Green 1990: 468. Russo 2003 refutes almost every aspect of Green's assessment of Hellenistic science, even after subtracting Russo's untenable theories from his overall case.

765. Quote of P. Green 1990: 469. I do not know what exactly Green means by "servomechanisms," which are by definition electronic devices (consult any common dictionary). If he means mechanisms that multiply human strength, the crane alone refutes him. If he means mechanisms that automate mechanical processes, the watermill alone refutes him, as do Roman sawmills and evidence of mechanized hammers. If he means industrial robotics that do not require electrical power, there was nothing of that kind before the 18th century, hence *after* the Scientific Revolution. Perhaps he means the adaptation of water power to more diverse industries, which began in the 14th century (see Reynolds 1983). Even supposing none of these applications existed in Roman times (again, arguments from silence are feeble here), there is no reason to assume comparable developments would not have taken place in the 3rd and 4th centuries if the peace, prosperity, and dominant zeitgeist of the 1st and 2nd centuries had continued.

766. Quote of Green: P. Green 1990: 467.

767. Interest in efficiency in the water supply is a central and continual concern of Julius Frontinus in his manual *On the Aqueducts of Rome*, as rightly noted by K.D. White 1984: 188.

768. Modern concepts of efficiency: See introduction to section 3.9 below. Ancient dreams of automation, imagining robot servants and laborers that would render slavery obsolete, were never connected to realistic technologies, but remained mere fantasies (like 20th century dreams of bubble cities and flying cars—or, still my favorite, the little pill that becomes a fabulous chicken dinner in *The Fifth Element*). For example: Aristotle, *Politics* 1.4.1253b-1254a (referencing Homer, *Iliad* 18.369–381 and Plato, *Meno* 97d-e) and Athenaeus, *The Dinnersages* 6.267e-270a (discussed cynically in P. Green 1990: 392). Although at the dawn of the 1st century A.D. the poet Antipater of Thessalonica praised the watermill as a labor-saving machine that would bring us back to a golden age without toil (*Palatine Anthology* 9.418), which is a more serious recognition of the value of automation, notably from the Roman era (see Reynolds 1983: 17, M.J. Lewis 1997: 66–69, and Humphrey et al. 1998: 31, with *OCD* 107, s.v. "Antipater (5)").

769. Vitruvius, *On Architecture* 9.pr.3–16 and 10.1.5–6 (e.g. 9.pr.4–8: discoveries in theoretical and applied mathematics; 9.pr.9–12: Archimedes' discovery of the principle of hydrostatics).

770. Galen, *On My Own Books* 11 (= Kühn 19.40). Galen repeats and elaborates this sentiment throughout his works, always including logic and empirical research in his methodological ideal. See related discussion in chapter seven of Carrier 2016 (on mathematics) and discussion here in section 3.7 (on method).

771. Quote of Cuomo: Cuomo 2001: 187–88.

772. Quote of Vernant: Vernant 1983: 289, 283 (cf. 287).

773. U.S. Naval manual cited: NAVEDTRA 1994 1–1 and 1–2. This is presently a textbook used by the officer training programs of the United States Navy.

774. Quoted remarks on Roman achievement: Marchis & Scalva 2002: 26. On Roman waterlifting machinery: Bowman & Wilson 2013: 273–305 (supplementing references on waterwheel technology in following notes).

Section 3.7 Was Roman Science in Decline?

775. Quote of Russo: Russo 2003: 266 (he offers several negative assessments of Roman science, none of which are demonstrated by any adequate evidence: 15, 215, 231–41, 264–70, 282–86, 318; yet ironically he challenges the basis of such assessments from other authors: 197–202). Contrast Russo's assessment with that of Chevallier 1993.

776. An example of this error on a grand scale is Stahl 1962 and 1971.

777. For modern mis-assessments of Pliny (and their recent correction) see earlier note.

778. Pliny discusses medicine in the 29th book of his *Natural History*, Celsus in his extant volumes *On Medicine*, both in Latin. Romans did not all agree with Pliny, e.g. Aulus Gellius (in *Attic Nights* 10.12) takes Pliny's credulity to task, somewhat unfairly according to Beagon 1992: 11 n. 31, but there would have been many laypeople of the day who could correct Pliny on many points. Similarly, Quintilian (in *Education in Oratory* 10.1.128) complains that Seneca was a brilliant man but relied too much on research assistants who sometimes led him into error.

779. For a relatively (and sometimes unfairly) negative assessment of Strabo see Aujac 1966.

780. P. Green 1990: 481. Farrington 1965 attempts a similar but even more inept argument.

781. See Dodds 1951 and note in chapter 1.3 on religious persecution in Classical Athens.

782. On various absurdities among 17th century scientists see: Russo 2003: 355–59, 363–64, 366–69, 385–88 (likewise, for Newton, Rossi 2001: 203–29); more examples in Zimmermann 2011. Ultimately there was nothing any more boneheaded in ancient scientific treatises than can be found in even the most respected authorities of the Renaissance.

783. Quote of Green: P. Green 1990: 480–81. Similarly, Moses Finley concedes "there were improvements of one kind or another," and "technical refinements," but insists these were only "marginal" and not "radical improvements," without defining either 'marginal' or 'radical' (Finley 1985: 109, 114).

784. Quote of Green: P. Green 1990: 481. He also complains of a lack of formal statistics and "advanced technical instruments" in antiquity (P. Green 1990: 457), even though neither existed until *after* the Scientific Revolution. Likewise for Zilsel's complaint that they didn't have periodicals (Zilsel 1945: 327). However, as noted in the previous section, the Romans must have had more advanced lathes than we are otherwise aware. Indeed it is ironic that (as also noted in the previous section) Green cites ancient precision tooling of nested cylinders to within a tenth of a millimeter, and yet he somehow thinks this was achieved without fine-calibrated lathes, which would have been needed for turning the wax molds to such a precise clearance.

785. Quote of Gwynn: Gwynn 1926: 146. Such dismissiveness, which can still be found (we opened with an example from Russo), is rightly criticized in Nutton 2013: 13–16 (though only for medicine, his remarks are as relevant for astronomy and physics) and also challenged by Chevallier 1993.

786. Galen's advances: See Galen, *On the Doctrines of Hippocrates and Plato* 2.4.33–39 and *On the Uses of the Parts* 7.14 (= M.T. May 1968: 367).

787. Sambursky 1962: 253–76. The same points (or claims even more ridiculous) are still echoed in more recent scholarship, e.g. Vernant 1983: 294–295 and 366, Reynolds 1983: 32–35, Lewis & Reinhold 1990: 2.210, and Stark 2003: 151–54 (with the same material almost verbatim in Stark 2005: 17–20, though adding more false assertions about ancient science and technology in 2005: 12–17). All of which are adequately refuted by the substance of the present chapter. As also (more succinctly) in Carrier 2010 (supported by Efron 2009).

788. Scientists not isolated from each other: Contrary to Sambursky 1962: 254–55. See examples in chapters three and four here, and throughout Carrier 2016.

789. No relevant disdain for shopwork and technology: Contrary to Sambursky 1962: 257–60. See discussion below and in chapter 4.6.

790. No significant opposition to changing or interfering with nature: Contrary to Sambursky 1962: 259–62. See discussion below.

791. No aversion to experiments: Contrary to Sambursky 1962: 261–70. See examples throughout sections 3.1 through 3.6.

792. No failure to mathematize the study of nature: Contrary to Sambursky 1962: 270–73. See examples in sections 3.3 and 3.4 (and even in biology: see discussion and sources in von Staden 1996: 88–90).

793. Did understand natural processes mechanically rather than organically: Contrary to Sambursky 1962: 273–74. See discussion below.

794. No rise in irrationality: Contrary to Sambursky 1962: 260–61, 274. See remarks above.

795. Confusing effects with causes: Sambursky 1962: 254–56. On the relevance of this point see section 1.1.

796. Quote of Sambursky: Sambursky 1963: 62.

797. Quote of Sambursky: Sambursky 1963: 63–66.

798. Quote of Edelstein: Edelstein 1963: 24–27.

799. P. Green 1990: 470.

800. P. Green 1990: 459.

801. P. Green 1990: 482. It should also be noted that Green has been deceived by medieval selectivity in preserving texts, creating the illusion of a rising interest in moral philosophy at the expense of physics and logic that actually never happened in antiquity: see Carrier 2016: 102–04.

802. P. Green 1990: 457. See the more reasonable analysis of Alexander 1990 and discussion in chapter seven of Carrier 2016.

803. P. Green 1990: 481.

804. P. Green 1990: 457.

805. Ben-David 1991: 301.

806. Ptolemy's *Almagest*, *Geography*, and *Harmonics* are good examples of his discussion of predecessors and his reliance and improvement on them, as are Galen's many treatises on anatomy and pharmacology, and likewise Hero's *Pneumatics*.

807. See discussion in Carrier 2016 (index, "eclecticism") and section 3.2 above. For further discussion of the eclecticism of Galen and Ptolemy see: Gottschalk 1987: 1164–71. For Ptolemy: *DSB* 11.201–02 (in s.v. "Ptolemy"). For Galen: Hankinson 1992. For Hero: Tybjerg 2005: 214–15. Galen specifically describes and advocates eclecticism in *On the Affections and Errors of the Soul* 1.8 and 2.6–2.7 (= Kühn 5.42–43 and 5.96–103) and Seneca effectively does the same in *Moral Epistles* 33. See also the 'eclectic' credo advocated in Celsus, *On Medicine* pr.45–47.

808. For Ptolemy's scientific epistemology: Huby & Neal 1989; Long 1988: 176–207; A.M. Smith 1996: 17–18; Barker 2000. For Galen's scientific epistemology: Frede 1981; Walzer & Frede 1985: xxxi-xxxiv; Iskandar 1988; J. Barnes 1993; Hankinson 1988: 148–50, 1991a: xxii-xxxiii and 109–10, 1991b, and 1992; M.T. May 1968: 45–64. For an early summary of both: Edelstein 1952: 602–04. Ptolemy's *On the Criterion* and Galen's *On Medical Experience* are prominent examples, as also Galen's On the Sects for Beginners and An Outline of Empiricism (for all three see translations and discussion in Walzer & Frede 1985, esp. xxxi-xxxiv), as well as his synthesis of epistemologies in *On the Doctrines of Hippocrates and Plato* 9, but much more important was Galen's treatise *On Demonstration*, which was specifically devoted to scientific method, and yet medieval scribes had no interest in preserving it (Nutton 1999: 166, §P.82,3–5 lists sources containing extant fragments of it, and Hankinson 1991b attempts to reconstruct Galen's scientific method from his extant works). On Galen's related interest in mathematics, and mathematical sciences and methods, see discussion in chapter seven of Carrier 2016 and example in section 3.6.VI. For examples of his commitment to an almost modern empiricism see Galen, *On the Method of Healing* 1.4, 2.7, 3.1, and 4.3 (= Kühn 10.31, 10.127, 10.159, 10.246) and *On the Affections and Errors of the Soul* 2.3 (= Kühn 5.66–69 and 5.80–90). That Galen's epistemology was influential in the development of modern scientific method is argued in Crombie 1953: 27–28, 40–41, 74–84, and Walzer & Frede 1985: xxxiv-xxxvi. I think one could argue the same of Ptolemy's as well (e.g. consider his anticipations Occham's Razor in *Planetary Hypotheses* 2.6 and *Almagest* 13.2).

809. Galen on unifying logic: See Kieffer 1964.

810. See chapter 2.7, discussion in chapter 1.2.III, and relevant discussion on Galen in chapter seven of Carrier 2016.

811. Hero, *Pneumatics* 1.pr. (see discussion in Argyrakis 2011). Hero also implies here that he had demonstrated other relevant principles in his treatise on waterclocks, which is unfortunately lost. Similar patterns are visible in various works by Galen and Ptolemy (see the end of sections 3.2, 3.3, and 3.4 for examples).

812. Ptolemaïs, *On the Difference Between the Aristoxenians and the Pythagoreans*, frg. 3, quoted in Porphyry, *Commentary on Ptolemy's Harmonics* 25.3–26.5. See also supporting quotation of Ptolemaïs in chapter 2.7 and the sources for Ptolemaïs in Carrier 2016 (index).

813. Countless examples of the slavery thesis exist in the literature, the following merely typical: Zilsel 1945: 328–29; Farrington 1946: 22–23; Vernant 1983: 283–84; and sources cited in P. Green 1990: 831 n. 81 and Pot 1985: 1.51–57.

814. Challenges to the slavery thesis can be found in Edelstein 1952: 579–81, 586–87, Brunt 1987, and Greene 1994: 26; even Sambursky 1962: 256–57 (though he still defends related ideas); and most recently Temin 2004 and Rihll 2008.

815. P. Green 1990: 458 vs. 469–70.

816. Slaves not efficient: Pliny the Elder, *Natural History* 18.4.21; Columella, *On Agricultural Matters* 1.pr.3.

817. Aristotle, *Politics* 8.6.1340b ("one must regard Archytas' rattle a good invention, which people give to children in order that while occupied with this they may not break any of the furniture").

818. Russo 2003: 130.

819. Simms 1995: 82–93 (quotes from 82 and 89).

820. P. Green 1990: 456 (similarly repeated: 473). This echoes Farrington 1946: 52–53, whose entire argument was already refuted by Edelstein 1952: 585–96.

821. Any art could become respectable: As supported by the various studies in Lévy et al. 2003.

822. Columella's program to make agriculture a science: See chapter seven of Carrier 2016.

823. "One must look elsewhere for the neglect of certain fields": Such as the hypotheses proposed in section 3.5.

824. Ben-David 1991: 301. Essentially the same claim appears in Edelstein 1963: 26; Finley, 1981: 180; Vernant 1983: 283; Pot 1985: 1.36–48; P. Green 1990: 458, 472; and more skeptically in Lloyd 1991: 162–63.

825. For example, "human intervention into the natural order of things was improper" according to Reynolds 1983: 32. He presents no evidence of this. The same assertion is made by P. Green 1990: 472, offering as his only evidence the claim that "the Greeks excelled in areas (e.g. hydrostatics) where movement was not in question," ignoring their equal mastery of mechanics and pneumatics, where movement was exactly in question.

826. "This has already been soundly refuted." For example: von Staden 1975. We have already seen evidence (in sections 3.2 through 3.4) that controlled experimentation existed in antiquity even beyond what von Staden documents.

827. "They filled the world with artificial roads," etc. As observed in Strabo, *Geography* 5.3.8, they did this not only for military use but to benefit commerce, as level and straight roads eased the transport of cargoes.

828. "They constructed artificial harbors," etc. For all these examples, besides evidence in section 3.6 and below, see Russo 2003: 203, 252–54. Also see Oleson 1984: 406–08, who despite advocating the contrary, actually refutes himself by listing numerous widespread examples of defying nature for the public good in repeatedly innovative and ingenious ways throughout antiquity.

829. Pavlovskis 1973 (with Humphrey et al. 1998: 413–16) provides considerable evidence that many Romans were proud of altering nature for their convenience. For extended examples see Pliny the Elder, *Natural History* 36.14.64–36.24.125 (praising several nature-altering projects), and Cuomo 2007: 75 (linking similar pride to Roman self-image).

830. Aristotle, *Physics* 2.8.199a-b.

831. Pseudo-Aristotle, *Mechanics* 1.847a.

832. Cicero, *On the Nature of the Gods* 2.60.150–52.

833. Cicero, *On Duties* 2.3.12–2.4.16.

834. Beagon 1992: 185.

835. Augustine quote: Whitney 1990: 52–54 (cf. Augustine, *City of God* 22.24).

836. Varro, *On Agricultural Matters* 3.17.9. See also Plutarch, *Life of Lucullus* 39.3. On Roman tunneling technology see M.J. Lewis 2001b: 197–216, 345–46.

837. Pliny the Younger, *Letters* 10.41, 10.42, 10.61, 10.62. See Peacock 2012 for a similar Trajanic canal project connecting the Suez with the Nile.

838. Tacitus, *Annals* 15.42–43. The very same contrast between praise and condemnation of technologies in Pliny the Elder is analyzed in Wallace-Hadrill 1990.

839. Indeed there was no anti-technology movement in antiquity comparable to the Luddites of the *modern* era (Binfield 2004), whose sentiment survives even to this day in such disparate movements as the Amish, Neo-Luddites, and ecoanarchists (Brende 2004, Zerzan 2005, S. Jones 2006).

840. P. Green 1990: 462.

841. Stark 2003: 152.

842. P. Green 1990: 461.

843. "This is all nonsense." As others have pointed out, e.g. Greene 1994: 26–27.

844. See examples in sections 3.2 through 3.4 above. Though Berryman 2002 and 2003 employ a highly restrictive definition of 'mechanical' she still finds such explanations evident in antiquity, and even the examples she rejects still qualify on any broader definition. And Berryman 2009 thoroughly demonstrates mechanization of nature was common across all disciplines.

845. Cicero, *On the Nature of the Gods* 2.34.88–2.35.88.

846. Vitruvius, *On Architecture* 9.1.2, 10.1.4. On the pervasive use of such mechanical analogies in Roman cosmology see Aujac 1993: 157–78 and Delattre 1998 (who adds the observation that even harmonic theories in astronomy equate the solar system with physical instruments).

847. Plutarch, *On the Face that Appears in the Orb of the Moon* 6 (= *Moralia* 923c-d).

848. Mechanical metaphors were typical: See Webster 2014, Russo 2003: 146–51, and von Staden 1997b: 201–03; and even van der Waerden 1963: 51–52 and Farrington 1946: x, 6–14 (with, e.g., *DSB* 6.428, in s.v. "Hippocrates").

849. See, for example, the methodological discourse in *Aetna* 29–93. On the *Aetna*'s attack on popular animism, and advocacy of mechanical explanations in place of divine, see Paisley & Oldroyd 1979: 2–6 and Goodyear 1984: 346–47.

850. For example: Galen, *On the Natural Faculties* 3.15 (= Kühn 2.210–11); Galen, *On the Uses of the Parts* 1.2–4, 1.19, 7.14 (= M.T. May 1968: 69–71, 103, 364–66). The body as instrument or machine was a widely understood metaphor, e.g. Marcus Aurelius, Meditations 10.38.

851. See, for example, Galen, *On the Uses of the Parts* 14.5 (= M.T. May 1968: 627). This mechanization of physiology had already begun with Herophilus: see von Staden 1996.

852. Physiology seen as an engineering matter: See discussion in Hankinson 1988.

853. See Vegetti 1995, Nutton 2013: 136–38, and discussion in section 3.2 above (although Erasistratus himself appears to have been a pantheist, cf. von Staden 1996: 95–96). As noted in section 3.2, the more atheistic Asclepiads shared a similar interest in mechanical explanation.

854. "Some scholars have claimed the ancients did not believe in divine design." Ben-David, 1991: 301; Stark 2003: 152.

855. Atheists did have incentive to be scientists: See the whole of Lucretius, *On the Nature of Things*, but, e.g., in 5.96 the whole of existence is explicitly called a machine (*machina mundi*).

856. Stark 2003: 154.

857. Despite Stark's contrary assertion (Stark 2003: 154), Aristotle argues *against* the idea that celestial bodies move according to their desires, and instead insists they move because of fixed and innate tendencies (cf. Aristotle, *On the Heavens* 2.1.283b-284a; similarly proposed in Ptolemy, *Planetary Hypotheses* 2.6: see Murschel 1995). And as we saw in sections 3.3 and 3.5, Aristotle did not command the field: several different explanations of celestial motions continued to be advanced and debated well into the Roman period.

858. Living things as machines: For example, see analysis of Seneca's use of such models in Taub 2003: 141–61.

859. L. White 1963: 282–83 (quoting R.J. Forbes). A similar 'argument from animism' is also advanced (rather ridiculously, considering the context) in Oleson 1984: 403.

860. In L. White 1963: 272–73, 275, 278, 286–91; White attempts to explain at least the first problem as resulting from differences in Christian theology between East and West.

861. Cyclical time argument: For example von Wright 1997: 2 (his only example is Parmenides, who was already obsolete even by Aristotle's day).

862. The entire idea is refuted on both facts and logic in Edelstein 1967: xx-xxiii, 29–30, 63, 121–27. That a cyclical model of time is not even incompatible with actual, anticipated, or even desired progress is also soundly argued in Burkert 1997: 34–38.

863. Stark 2003: 152, 153 (his only examples are also Parmenides, certain unnamed "Ionians," some alleged opinions of Plato, and misquotes of Aristotle).

864. Lloyd 1990: 71.

865. Aristotle, *Metaphysics* 1.1.981b.

866. Aristotle, *Politics* 2.5.1263b-1264a.

867. Aristotle, *On Poetry* 4.1449a (a belief that again may have been analytically reasonable, given Aristotle's definition of tragedy and his own aesthetic ideals).

868. Aristotle, *On Poetry* 4.1448b4–1449a32.

869. Stark 2003: 153.

870. Aristotle, *On the Heavens* 1.3.270b.

871. Aristotle, *Politics* 7.10.1329b.

872. Aristotle, *Metaphysics* 12.8.1074b: *kata to eikos pollakis heurêmenês eis to dunaton hekastês kai technês kai philosophias, kai palin phtheiromenôn, kai tautas tas doxas ekeinôn hoion leipsana perisesôsthai mechri tou nun*. See also Plato, *Laws* 3.677a-678c.

873. Rihll 2002: 14 n. 36.

874. Marcus Aurelius, *Meditations* 11.1.3 (cf. also 8.6).

875. That it is the *form* of things that never changes: Marcus Aurelius, *Meditations* 2.14.2 (meaning the natural laws governing the universe: 9.35 and 12.21). Though he does adhere to the cyclic view of history: Marcus Aurelius, *Meditations* 7.19 (with 7.18, 7.25, 9.19, 9.28).

876. Marcus Aurelius, *Meditations* 7.49 (cf. also 10.27).

877. Marcus Aurelius, *Meditations* 7.67.1, 8.11, 8.26, 10.9. See discussion of Aurelius in chapter 4.2.

878. Ecclesiastes 1:9–14.

879. Apocalypticism ending science: See chapter 5.6.II for evidence of this consequence in early Christianity.

Section 3.8 Ancient Tales of Decline

880. Caplan 1944: 308 (whose analysis of ancient claims of decline in Roman oratory is in many respects outdated but still useful for the general point). Tacitus was well aware of this human tendency to find fault with one's own generation (cf. Tacitus, A Dialogue on Oratory 11).

881. Seneca, *Natural Questions* 7.31–32.

882. Seneca, *Moral Epistles* 95.23.

883. "Popularity of schools and public lectures": Discussed throughout Carrier 2016.

884. Seneca, *Moral Epistles* 95.15–29. Others shared his belief that new diseases were caused by immoral living, cf. Nutton 2013: 36, 170 and Cuomo 2007: 2.

885. Such a tirade from Papirius Fabianus is quoted by Seneca's father (Seneca the Elder, *Controversies* 2.1.10–13; with a similar but unattributed tirade at 5.5.1–2). Such pining for simpler times was not uncommon in antiquity (cf. Pot 1985: 1.29–35) and is just as common today (see previous note on Neo-Ludditism). This could be the same Papirius Fabianus the noted natural philosopher (see section 3.5).

886. Neronian era politics: On this aspect of 1st century attacks on cultural decadence: Beagon 1992: 18.

887. Pseudo-Seneca, *Octavia* 377–436.

888. Seneca, *Moral Epistles* 90. For a partial commentary see Kidd 1988: 960–71 and D. Russell 1974: 90–95. Nearly every passage cited from Seneca in section 3.6 includes his condemnation of one technology or other.

889. Seneca, *Moral Epistles* 90.8–10. Further exposing his hyperbole, in the very next letter he praises the city of Lyons for its magnificent buildings: Seneca, *Moral Epistles* 91.2. Similarly, while Seneca says it was far better for Diogenes to abandon the cup than for Daedalus to invent the saw (Seneca, *Moral Epistles* 90.14), we can hardly believe Seneca never drank from a cup (or could ever have tolerated living in a society that never used a saw). On Seneca's characteristic hypocrisy in matters of wealth and luxury see Griffin 1976: 286–314, who sympathetically argues it was only a rhetorical device.

890. "His opinion on the matter was being ignored." Hence, for example, his own recognition of this fact in Seneca, *Moral Letters* 90.19.

891. As is essentially argued in J.-M. André 2003.

892. I argue Seneca saw science as "a quest to know and understand the natural world" in section 3.9.II (see also chapter 4.4). Though Seneca's 88th epistle contains a parallel attack on the liberal arts, it also elevates natural philosophy as a worthy enterprise, and recognizes the liberal arts as its scientific tools, as we shall see in chapter 4.6.I (though we have already seen an example of this in chapter 2.7).

893. Seneca, *Natural Questions* 1.17.2–3.

894. Petronius, *Satyricon* 88.

895. Petronius, *Satyricon* 88.1–7.

896. Columella, *On Agricultural Matters* 1.pr.31. Sober histories of art from the early empire confirm the abundant survival of actual paintings and sculptures along with evidence of continuing work by contemporary painters and sculptors of exceptional quality (a fact archaeology has confirmed): cf. Callistratus, *Descriptions*; Philostratus, both the Elder and Younger, who each wrote an extant *Images*; Pliny the Elder, *Natural History* 35; and numerous passages throughout Pausanias, *Description of Greece*. See also: *OCD* 1062–64 (s.v. "painting (techniques)," "painting, Greek," and "painting, Roman") and *OCD* 1332–35 (s.v. "sculpture, Greek" and "sculpture, Roman").

897. Sullivan 1968: 202–12.

898. Walsh 1970: 94–97 (quotes: 96–97), cf. also Walsh 1996: 183–86.

899. Slater 1990: 94–95.

900. Slater 1990: 208, 223–26.

901. Courtney 2001: 133–43 (quote: 140).

902. Habermehl 2006: 126–48.

903. Habermehl 2006: 135–39 (quote: 138).

904. Pliny the Elder, *Natural History* 35.1.1–35.2.8.

905. On the uninfluential conservatism of Vitruvius: Rowland & Howe 1999: 10–13, 17–18. This was only in aesthetics. In practical matters Vitruvius was a progressivist (see section 3.9.II).

906. Pliny shows advances in the arts: This fact is thoroughly surveyed by Jex-Blake et al. 1968.

907. Pliny on scientific progress: This and following: Pliny the Elder, *Natural History* 2.45.116–118. Indeed, in all of this I concur with the analysis of Meissner 1999: 209–16.

908. Pliny the Elder, *Natural History* 2.81.191–192.

909. Pliny the Elder, *Natural History* 15.17.57.

910. Grafting auger: Pliny the Elder, *Natural History* 17.25.116 (its invention and advantages are described in Columella, *On Agricultural Matters* 4.29.15–16).

911. Similarly, it is sometimes claimed Pliny disparaged all attempts to calculate the distance of the planets as "madness," but in actual fact he said this only of attempts to calculate the size of the entire universe (Pliny the Elder, *Natural History* 2.1.3–4 and 2.21.85–88), which was a reasonable opinion at the time—even modern science has failed to accomplish this.

912. Pliny the Elder, *Natural History* 14.1.3–7.

913. Pliny the Elder, *Natural History* 25.1.1–3. Condemning the selfishness of not publishing one's discoveries was a trope among ancient science writers (e.g. Vitruvius, *On Architecture* 7.pr.1; Galen, *On Conducting Anatomical Investigations* 2.1 and 14.1).

914. Pliny the Elder, *Natural History* 25.5.1, with 25.1.1–25.2.4, 25.6.16, 29.1.1, and especially 26.6.11 and 27.1.1.

915. Pliny also says no one had written about medicine in Latin (Pliny the Elder, *Natural History* 39.1.1), which was also not true (Varro, Largus, and Celsus had all done so, and no doubt others as well). My analysis here of Pliny's criticism of contemporary medicine is confirmed by Hahn 1991 and French 1994: 223–25.

916. In general the Roman elite had shown some hostility to Greek scientific medicine in the 2nd century B.C. but had fully embraced it a century later: Scarborough 1993; Marasco 1995; Nutton 1993a and 2013: 160–74.

917. The entire preface of Pliny's *Natural History* addresses Titus intimately (they were close friends and had served in combat together), though under his cognomen Vespasian. Since Pliny died unexpectedly less than two months after Titus became emperor (in June of 79 A.D.; Pliny was killed by Vesuvius in August), clearly most of the *Natural History* had been written under (and hence to) the elder Vespasian, although it must have been completed only just before Pliny's death, in time for him to craft an elegant preface to Titus. Cf. *OCD* 1162, 1487–88, 1545 (s.v. "Pliny (1) the Elder," "Titus (Titus Flavius Vespasianus)," and "Vesuvius").

918. Pliny the Elder, *Natural History* pr.6.

919. *Aetna* 252–77.

920. Status of oratory: Tacitus, *A Dialogue on Oratory* 29–32. See discussion in chapters five and six of Carrier 2016.

921. Diodorus Siculus, *Historical Library* 2.29.6.

922. "Even Diodorus was not against culturally useful advances." See example in section 3.9.II below. Likewise, 'complaints' of rising scientific specialization indicate a rising complexity of scientific knowledge, which is actually a consequence of progress, not a sign of decline (von Staden 2002; e.g. Cicero, *On the Orator* 3.23.132; Galen, *To Thrasybulus* 24 = Kühn 5.846–51 and *On the Parts of Medicine* 2; Philostratus, *Gymnastics* 15; etc.).

923. Frontinus, *Stratagems* 3.pr.: *Depositis autem operibus et machinamentis, quorum expleta iam pridem inventione (nullam video ultra artium materiam), has circa expugnationem species stratêgêmatôn fecimus: ... Ex contrario circa tutelam obsessorum*.

924. So in *nullam video ultra artium materiam*, *video* must mean 'attend to' (and not 'see' or 'know'), *ultra* must refer only to the rest of his present chapter, and *nullam...materiam* must mean passages he could have collected on the subject, not future technologies. Both I and Bennett correctly take *artium* in the same sense as the only other plural of *ars* in the same treatise (*artibus bellandi*, cf. Stratagems 1.8), here referring back more specifically to the arts involved in the development of war machinery, and thus to treatises on that subject from which he could have drawn passages for his present collection. Hence most likely *expleta iam pridem inventione* probably does not refer to the discovery (i.e. invention) of machines, but the rhetorical process of *inventio*, i.e. collecting and filling out *topoi* as Frontinus does throughout the Stratagems.

925. Galen, *On Conducting Anatomical Investigations* 14.7 (compare with Pliny the Elder, *Natural History* 2.45.118; another similar seafaring analogy appears in Seneca, *Natural Questions* 5.18.11–14). Other parallels (though unrelated here) include the fact that both Pliny and Galen marvel at the anatomy of a flea and discuss it at some length (Pliny the Elder, *Natural History* 11.1.1–4 and Galen, *On the Uses of the Parts* 17.1 = Kühn 2.448–49 = M.T. May 1968: 731–32; there is also a reference to the study of flea anatomy in Tertullian, Treatise on the Soul 10, possibly inspired by either).

926. Galen, *That the Best Doctor Is Also a Philosopher* 2 (= Kühn 1.57).

927. Galen, *On Examinations by Which the Best Physicians Are Recognized* 1 (esp. 1.4; cf. also 9.2 and 13.2–3). See relevant discussion in chapter 4.3 for evidence in Galen exposing the hyperbole. Of course, many trained doctors were slaves, but by no means all, nor was the quality of their education necessarily inferior.

928. Galen, *On the Therapeutic Method* 2.5.16 (cf. also 1.1).

929. Nutton 1972 and 2013: 205–06, 211–13, 220–21.

930. Galen, *On Conducting Anatomical Investigations* 2.1 (= Kühn 2.280–83) and *On My Own Books* Kühn 19.9.

931. See discussion of Roman medical education in chapter seven of Carrier 2016.

932. Cicero, *On the Boundaries of Good and Evil* 5.20.57. See discussion in chapter 4.2.

933. Africa 1967: 72.

934. Suetonius, *Vespasian* 18: *mechanico quoque grandis columnas exigua impensa perducturum in Capitolium pollicenti praemium pro commento non mediocre optulit, operam remisit praefatus sineret se plebiculam pascere*.

935. Graves & Grant 1979: 288. This is an example of a pervasive problem throughout Graves' translation of Suetonius, which Michael Grant laments in the introduction to the revised edition (ibid.: 10), and claims to have corrected with his revision, evidently missing this one.

936. Casson 1978 and Brunt 1980. Kevin Greene sides with Casson (Greene 2000: 49–50).

937. Brunt 1980: 81.

938. For example: *pollicens* means "bid, promise, offer"; *exigua impensa* means "low cost, small expense"; *opera* means "work, job, employment"; and *mechanicus* would here mean "engineer," who was often the contractor arranging an entire works project, not just building the machinery.

939. For example: Vitruvius, *On Architecture* 10.2.13–14 relates a similar story about the engineer Paconius, who developed a new method of hauling blocks that was supposed to be cheaper but turned out to cost a great deal more than established methods.

940. The bowl remark is in Petronius, *Satyricon* 52. If it needs to be said, Daedalus, Niobe, and the Trojan Horse all existed at different times in mythic history, at different places, and in completely unrelated stories (which makes this comparable to saying Abraham Lincoln had sealed Robin Hood in Al Capone's vault).

941. Petronius, *Satyricon* 51. Notably, the name of the emperor is not given. He is only identified as Tiberius by later authors (as we shall see). Petronius may have intended it to be Nero.

942. Though blown glass (which had only recently been invented) is indeed flexible and repairable in its melted state, even the nitwit Trimalchio distinguishes his imagined 'unbreakable' glass as something notably different from ordinary blown glassware (though the behavior of melted glass could have inspired someone to imagine the possibility of it retaining this property when cooled). Attempts to argue that aluminum was meant (or other substances) are refuted in Eggert 1995.

943. Pliny the Elder, *Natural History* 36.66.195 and 36.67.199.

944. Cassius Dio, *Roman History* 57.19–21.

945. In fact Hero, *Mechanics* 3.10–12 (cf. Drachmann 1963: 108–09) discusses several techniques for righting walls, columns, and porticos that have begun to pitch or lean, so this was evidently a common and expected skill among ancient engineers, and not remarkable as Dio claims.

946. Cassius Dio, *Roman History* 57.21.5–7. Whether this story bears any connection to other ancient stories about glassbreaking is a question for another time (e.g. Seneca, *On Anger* 3.40; Pliny the Elder, *Natural History* 37.10.29; Cassius Dio, *Roman History* 54.23.2–4; etc.).

947. For example: Trowbridge 1930: 110–12; Simms 1995: 108 n. 7.97; E.M. Stern 1999: 441–42; Greene 2000: 46–47.

948. I will not discuss incidental impediments that have no cultural or institutional explanation, such as a need for a telescope or printing press, which were happenstance inventions that could have occurred at any time (see chapter 1.1 and introduction to the present section). But the claim that "scientific advance in the ancient world was hampered generally by the lack of a reliable means of calculating time" (M.R. Wright 1995: 127) is untrue. Astronomers routinely used a standard equinoctial hour and knew how to accurately convert seasonal hours to standard hours, and had several fairly sophisticated technologies for telling time, including sundials, waterclocks, and diopters (see Hannah 2009; and general sources in section 3.3).

949. Mettius Pompusianus: See Arnaud 1983, with *OCD* 951 (s.v. "Mettius Pompusianus").

950. Suetonius, *Domitian* 10.3.

951. Cassius Dio, *Roman History* 67.12.2–5.

952. Domitian's capricious execution of an acting student is reported in Suetonius, *Domitian* 10.1.

953. This question of human dissection has been widely discussed: Edelstein 1935; M.T. May 1968: 22–24, 40–41; Kudlien 1970: 21; P. Fraser 1972: 1.348–52 and 2.504–14; Lloyd 1973: 75–78; Ferngren 1982; Fischer 1984; Iskandar 1988: 165–67; von Staden 1989: 139–53; Debru 1994: 1725–26 n. 40; Byl 1997.

954. On his caution: Galen, *On the Uses of the Parts* 1.22 (= M.T. May 1968: 107–08). Evidence of human anatomical knowledge: C.J. Singer 1956: xxi-xxiii. Evidence Galen and his contemporaries had dissected humans: Hankinson 1994a: 1786; and evidence to follow.

955. See von Staden 1992.

956. Pliny the Elder, *Natural History* 28.2.5: *aspici humana exta nefas habetur*. But contrast this with Cicero, *Prior Academics* (= *Lucullus*) 2.39.122.

957. Apuleius, *Apology* 38. And see the Senecan legal case discussed below.

958. Rufus, *On Naming the Parts of the Body* 1.

959. Galen, *On the Anatomy of the Uterus* 5 (= Kühn 2.895). Conspicuously absent here is any mention of Herophilus having *vivisected* humans (in fact, in all his extant writings, Galen never mentions anyone ever having done this), which I think casts doubt on the tale (see section 3.2). Human vivisection was certainly not going on in the Roman period, despite irrational fears of it, as reflected in a mock trial of a Roman doctor accused of murder by vivisection in Quintilian, *Major Declamations* 8 (cf. Ferngren 1982 and 1985).

960. Celsus, *On Medicine* pr.23–26, pr.40–44, and pr.74–75 survey various facts and opinions on the matter of human dissection.

961. Celsus, *On Medicine* pr.44. Aristotle said essentially the same of all dissection in his *Parts of Animals* 1.5.645a27–37.

962. Celsus, *On Medicine* pr.74–75.

963. A late medical source (Vindicianus, *Gynecology* pr.) lists among those who dissected human corpses several Roman anatomists, including Rufus, Lycus, and Pelops, though he might have assumed this more than known it (von Staden 1989: 52, 60, 189). Augustine, *City of God* 22.24, and others in late antiquity, refer to continuing dissections of human cadavers, though in contexts that could be rhetorical (cf. von Staden 1989: 188–89, 235). Even more inconclusive is a visual depiction of what appears to be a human dissection in an early 4th century catacomb painting (see note in chapter 1.3).

964. Galen, *On Conducting Anatomical Investigations* 3.5 (= Kühn 2.384–86). Celsus had said convicts were also the source for Herophilus and Erasistratus. Aborted or miscarried fetuses might also have been dissected in the Roman period, as they had before (cf. Nutton 2013: 220).

965. Galen, *On Conducting Anatomical Investigations* 1.2 (= Kühn 2.220–22; inspecting human skeletons is repeatedly referred to as something that happens only by chance: 1.2 = Kühn 2.223–24; 14.1 = Kühn 2.229).

966. Galen, *On Bones for Beginners* 4.750, 6.754, and 11.762, which mentions examining both human and ape bones, and speaks generically of the fact that for research use all bones are typically boiled and dried (cf. C.J. Singer 1952). But according to Galen, *On Conducting Anatomical Investigations* 14.1 (= Kühn 229), they are typically not cut out but rotted out, as for example by burying apes "for four months or more in earth that is not dry" and then exhuming them. So it is worth noting that burying and exhuming human bodies, even for science, would have been illegal (see later note).

967. Galen, *On Conducting Anatomical Investigations* 3.5 (= Kühn 2.385).

968. Galen, *On the Composition of Drugs by Class* 3.2 (= Kühn 13.604).

969. That exhuming the buried was both sacrilegious and illegal under the Romans (as it probably had always been): Gaius, *Institutes* 2.2–10 and *Digest of Justinian* 47.12.1 (cf. 47.12.3.2–7, 47.12.8, 47.12.11).

970. Seneca the Elder, *Controversies* 10.5.17 ("Parrhasius and Prometheus"). For scientific analysis: Fischer 1984. For historical analysis: Rouveret 2003. For literary analysis (and technical background on Parrhasius): Morales 1996.

971. *OCD* 1190 (s.v. "Porcius Latro, Marcus").

972. Seneca the Elder, *Controversies* 10.5.19.

973. "Similar problems vexed Renaissance and early modern attempts to secure human cadavers." Sawday 1995.

974. Galen, *On Conducting Anatomical Investigations* 1.2 (= Kühn 2.224–25).

975. Galen, *On Conducting Anatomical Investigations* 3.5 (= Kühn 2.383–84 and 2.386).

976. "More harmless experimentation on live humans." Surveyed in Debru 1994: 1725–30.

977. Ferngren 1985.

978. Real decline: Cohen 1994: 253 (cf. Lloyd 1973: 154–78).

979. Accordingly, Collins 1998: 501–04 summarizes the markers of decline as (a) a significant loss or neglect of the knowledge previously achieved, (b) an ossification of the knowledge preserved, and (c) an obsession with the logical refinement of ideas rather than a search for new evidence. The middle ages qualifies on all three counts.

980. Crombie 1997: 49, 52.

981. Better known as the *De Rebus Bellicis*, cf. E.A. Thompson 1952. Even the earlier hack, Athenaeus the Mechanic, whose treatise *On War Machines* is also relatively weak, nevertheless produces superior work (see note on him in section 3.4).

982. *On Matters of War* 17 (cf. E.A. Thompson 1952: 51–54, 77–78, 119–20). Though the text does not specify how many pairs of wheels, the drawing in the manuscript depicts three, and these drawings originate with the author—and even if poorly copied the number of wheels is unlikely to have changed. See also Landels 2000: 15–16, who likewise finds the description impractical, and Russo 2003: 139, who rightly suggests that the idea may have had more realistic precedents now lost. Otherwise, an engineer like Hero would have heaped ridicule on this presentation, just as Galen had on a ridiculous invention proposed by a similarly inexpert fantasist (cf. Galen, *On Conducting Anatomical Investigations* 7.16 = Kühn 2.643–44), though Galen pokes fun not so much at the impracticality of the tool (an Erasistratean resector) as the fact that it was never made or used.

983. If one man produces an effective power output of 75 Watts, then 170 men = 12,750 Watts. If an ox produces an effective power output of 450 Watts, then 6 oxen = 2,700 Watts, barely a fifth of a trireme's power train (for the relative power output of man and ox: Hicks 1997). A trireme had about 170 oarsmen, but a quadrireme about 220 and a quinquireme 300 (hence 16,500 and 22,500 Watts). Though men and animals can triple their power output in short bursts (thus tripling all Wattage figures, e.g. Landels 2000: 166 estimates a trireme's ramming power at over 30,000 Watts), this makes no relative difference. I use cruising power for ease of comparison, though notably even at *maximum* power six oxen cannot equal even a trireme's *cruising* power. For the oarage of triremes and polyremes see Meijer 1986: 36–37, 119–20 and Foley & Soedel 1981: 154–57. Even larger warships were deployed in the Greco-Roman period, though with less frequency, cf. Meijer 1986: 115–46 and Foley & Soedel 1981.

984. E.A. Thompson 1952: 54.

985. Needham 1971: 4.2.413–35 (cf. also 4.3.476 and 4.3.688–89, with 4.3.681 note b). The most common dragon boat had four wheels powered by 42 men with an estimated ramming speed of 4 knots (half that of a trireme). Smaller two-wheel models were powered by 28 men. Larger 11-wheel versions were known, but the largest (and rarest) had 23 wheels powered by more than 200 men. Though at a length of 360 feet this monster was so large it could never have outrun or outmaneuvered a trireme, it would certainly destroy any it managed to hit. Needham also says dragon boats were not seaworthy and thus were deployed on inland waters (effective small-river deployment may have been one advantage over a trireme) and, though used to ram, were mainly deployed as platforms for artillery. Needham's estimates of dragon boat tonnage are implausible so I won't consider them, but regardless of their displacement their power output in Watts would be 2,100 (small), 3,150 (medium), 7,500 (large), and 15,000 (giant), so a 6-oxen paddleboat would have barely outperformed a small dragonboat (see previous note). Another serious defect of ox power in combat is that it would be impossible to reverse without a complex variable transmission, a problem clearly unimagined by the medieval ox-boat fantasist.

986. For background see *ODCC* 484 (s.v. "Dionysius (4) the Great, St.").

987. On 'intelligent design' driving scientific research in Galen's work see Hankinson 1988. Galen was agnostic about whether there had been a singular moment of creation in the past, but he fervently believed the Mind of God had arranged the universe and its contents intelligently.

988. On such palimpsests see note in section 3.4.

989. Galen, *On the Therapeutic Method* 1.4.1–3 explains its relevance to making scientific progress. This is similar to Galen's *On Conducting Anatomical Investigations*, which is entirely devoted to the question of how to advance the field of anatomy: only half of this survived in Greek, the other half in Arabic (*On Dissection* also appears to have survived in Arabic, cf. Ormos 1993). And no one appears to have followed its advice.

990. Sections 3.1 through 3.5 document countless examples of known losses of scientific books, which entail many more unknown losses, since it is usually only by accident that we know even of lost titles. In respect to technology the same is argued in Oleson 2004 and Greene 1992.

991. A transformation (of decline) documented in Elsner 1995. Paralleling science and the visual arts, P. Harrison 1998 establishes a similar shift in the literary arts (including biblical interpretation), moving away from realism (e.g. literalism and naturalism) in the 4th century, and back again in the Renaissance (thus contributing to the restoration of scientific progress).

992. See, for example, Russo 2003: 59–60, 224–27. Other indicators of decline in the medieval period are surveyed in J. Russell 1987 and Mazzini 2012 (and on technological and economic decline, see discussion and references in section 3.6.IV above).

Section 3.9 Ancient Recognition of Scientific Progress

993. Claiming none: Zilsel 1945; Stark 2003: 153. Refuting with examples: Edelstein 1952: 575–76 and 1963: 19–22, and esp. Edelstein 1967; Cuomo 2000: 96; Russo 2003: 211–12.

994. Zilsel 1945: 327.

995. Edelstein 1967. According to the foreword by Jack Goellner (ibid.: vii), Edelstein only completed four of eight planned chapters before his death, bringing his analysis up to 30 B.C. (quite short of his goal of 500 A.D.), though in fact citing evidence up to 80 A.D.

996. Dodds 1973. Dodds did not claim to 'refute' Edelstein as Oleson 1984: 401 implies, but in fact often confirms Edelstein's findings, especially for the idea of scientific progress.

997. Edelstein 1967: xiv-xv.

998. Edelstein 1967: 142–48 (scientists), 101–18 (Plato), 19–29 (Aristotle), 158–80 (Romans).

999. Edelstein 1967: 176. That any keen observer of the time would have seen abundant progress in these areas is demonstrated in the first half of the present chapter.

1000. For discussion of conceptual issues related to identifying different ideas of progress in various periods of history see Podlecki 2005: 16–27; G. Campbell 2006: 39–60, 164–66; and Mazlish et al. 2006 (with Carrier 2007).

1001. Novara 1982.

1002. Zilsel 1945: 326. Like most work of such an early date, Zilsel's understanding of ancient science and technology is obsolete, and effectively refuted by the rest of the present chapter.

1003. Quoting von Wright 1997: 2–3.

1004. As suggested in section 3.6.VI.

1005. See von Wright 1997. The same argument is concisely made in P. Harrison 2007, while Pot 1985 provides an extensive survey of theories of how and why this link was eventually made, as well as positive and negative responses to technological progress in modern times (and a wide variety of modern ideas of progress through technology).

1006. Burkert 1997: 38 (cf. 38–43).

1007. Quotes from: Burkert 1997: 41; Crombie 1997: 53; Edelstein 1967: xxxiii.

1008. Quoted in Edelstein 1967: xvii.

1009. Edelstein 1967: xviii (against the idea that fatalism or pessimism ruled the day: xxiii-xxvii). See also Zhmud 2006: 16–22, 77–81, 210–13.

1010. The relevant works of Vitruvius, Hero, Seneca, and Pliny the Elder, for instance, are filled with examples (such as the many references to them already in section 3.6). The prospect of new technologies had been voiced at least as early as Theophrastus (cf. Theophrastus, *On Stones* 60, with Caley & Richards 1956: 198–204) and had been identified as a valuable result of experimentation and theoretical knowledge as early as Philo (cf. Philo of Byzantium, *Siegecraft* 4.1–5, 4.19 = Marsden 1971: 107–09, 121–23 = DeVoto 1996: 5–9, 28–29).

1011. Tertullian, *On the Soul* 30.

1012. Oleson 2004: 65.

1013. Thucydides, *Peloponnesian War* 1.71.2. Similarly in Polybius, *Histories* 10.47.12 (in the context of a discussion of the value of progress in the development of telegraphy: 10.43–47).

1014. Plato, *Hippias Major* 281d-282b.

1015. Zhmud 2003 and 2006.

1016. In a lost treatise quoted by Iamblichus and Proclus: cf. Burkert 1997: 32–33.

1017. Aristotle, *Metaphysics* 1.1.980a-982a.

1018. Aristotle, *Sophistical Refutations* 3.34.183b-184b.

1019. Aristotle, *Politics* 2.8.1268b-1269a.

1020. Aristotle, *Nicomachean Ethics* 1.7.1098a.

1021. Aristotle, *Metaphysics* 13.1.1076a.

1022. Aristotle, *Metaphysics* 2.1.993a-b.

1023. Aristotle, *On the Heavens* 2.5.287b-288a. For another example (in apiology) see section 3.1. For these and other examples of Aristotle's enthusiasm for progress see Edelstein 1967: 19–29. On passages suggesting the contrary only when taken out of context see section 3.7.IV.

1024. Lucretius, *On the Nature of Things* 5.332–37 (cf. 5.1448–57). Various aspects of the Lucretian attitude toward progress are discussed in Novara 1982: 313–84. (Lucretius was not actually the first to describe Epicurean philosophy in Latin: see note in chapter 1.2.I.)

1025. Diodorus Siculus, *Historical Library* 1.1–1.2. For his more conservative side see example in section 3.8.I, but his generally positive view of cultural progress is argued in Sacks 1990.

1026. Diodorus Siculus, *Historical Library* 1.2.1, using *epistêmas kai technas*, "[systematic] knowledge and [formal] skills."

1027. Diodorus Siculus, *Historical Library* 5.37.4, using *technitês*, "craftsman," and *philotechnon kath' hyperbolên*, "exceptionally brilliant." Dalley & Oleson 2003: 19–22 suggests the possibility that 'craftsman' refers to an unknown inventor of the waterscrew, which Archimedes only 'discovered' already being used in Egypt (and he was only the first to analyze it mathematically in terms of basic physics), but Oleson is rightly skeptical of this reading (as am I) since the context is certainly the mechanical genius of Archimedes and not his luck or his books.

1028. Polybius, *Histories* 8.7 (referring to Archimedes' mechanical defenses of Syracuse). See further examples of the valorization of Archimedes in chapter 4.2, 4.5, and 4.6.I.

1029. Philo of Byzantium, *Siegecraft* 4.19 (= Marsden 1971: 121–23 = DeVoto 1996: 28–29). Philo's attitude toward progress is discussed in Cuomo 2007: 51–52.

1030. Strabo, *Geography* 1.2.1.

1031. Cicero, *On Divination* 1.49.109 and *Prior Academics* (= *Lucullus*) 2.5.14.

1032. Cicero, *On Divination* 1.49.111 (quote; cf. also 1.56.128 and 1.57.131) and 2.3.9–2.5.12 (that observation, not revelation, will lead to progress in knowledge).

1033. Cicero, *Tusculan Disputations* 3.28.69: *brevi tempore philosophiam plane absolutam fore*.

1034. "Cicero was also a fan." Argued in Novara 1982: 257–70.

1035. Cicero, *Tusculan Disputations* 1.25.61–1.26.65.

1036. Rowland & Howe 1999: 16–17.

1037. Vitruvius, *On Architecture* 10.1.4: *ut essent expeditiora, alia machinis…nonnulla organis, et ita quae animadverterunt ad usum utilia esse studiis, artibus, institutis, gradatim augenda doctrinis curaverunt*. He follows with examples in 10.1.5–6.

1038. Vitruvius, *On Architecture* 2.1.1–9. A similar recognition of the arts and sciences as a cumulative and beneficial process of discovery on which civilization was founded is argued even by the Platonist philosopher Maximus of Tyre in *Orations* 6.2, and is a notion repeated by other ancient authors (see Lovejoy & Boas 1935 and G. Campbell 2006: 39–60, 164–66).

1039. Vitruvius, *On Architecture* 7.pr.1.

1040. Vitruvius, *On Architecture* 7.pr.10 (example: 7.pr.11–16).

1041. Athenaeus the Mechanic, *On War Machines* 31.12–32.2, following with an entire section devoted to innovation (see discussion in Whitehead & Blyth 2004: 36–39). This attitude is evident across the Roman engineering profession: Kolb 2015.

1042. Apollonius of Citium, *On Joints according to Hippocrates* 23–24 (cf. Potter 1993: 119). For more on this Apollonius see relevant note in section 3.2.

1043. Hero of Alexandria, *Pneumatics* 1.pr.1.

1044. Hero of Alexandria, *On Constructing Automata* 2.20.1–5 (= Murphy 1995: 3–4). See discussion in Tybjerg 2005: 211 and Rausch 2012.

1045. Hero of Alexandria, *Mechanics* 3.1 (cf. Drachmann 1963: 94).

1046. Cuomo 2002. See related discussion in chapter 2.7.

1047. Hero of Alexandria, *Metrics* 1.pr.1.

1048. Columella, *On Agricultural Matters* 1.pr.7.

1049. Columella, *On Agricultural Matters* 1.pr.10–21 and 1.pr.29.

1050. Columella, *On Agricultural Matters* 1.pr.3 and 1.pr.5.

1051. Celsus, *On Medicine* pr. and 7.pr.

1052. Celsus, *On Medicine* pr.26 (cf. pr.40 for those who argue the contrary; and pr.74 for Celsus' own opinion on the matter).

1053. Dioscorides, *On Medical Materials* 1.pr.

1054. Seneca, *Natural Questions* 6.5.2–3.

1055. Seneca, *Moral Epistles* 33.10–11.

1056. Seneca, *Moral Epistles* 64.4–8.

1057. Seneca, *Moral Epistles* 79.6. See discussion in chapter 4.4 of this expedition as well as the poem *Aetna*, which may have been the result of it.

1058. Seneca, *Natural Questions* 7.2.3.

1059. Seneca, *Natural Questions* 7.2–3, 7.25.3–7 and 7.30.2.

1060. Seneca, *Natural Questions* 7.25.4–5.

1061. Seneca, *Natural Questions* 7.25.7.

1062. Seneca, *Natural Questions* 7.30.3–4.

1063. Seneca, *Natural Questions* 7.29.3.

1064. Seneca, *Natural Questions* 7.30.5.

1065. Seneca, *Natural Questions* 7.30.2, 7.30.6, 7.31.1.

1066. Seneca, *Natural Questions* 7.30.6 (cf. also 3.pr.1). This equation of scientific research with the sacred mysteries was not unique: see chapter 4.2 and further discussion in 4.4.

1067. See discussion in section 3.8.

1068. Seneca, *Natural Questions* 7.32.4.

1069. For a broader discussion of Pliny's faith in progress see Beagon 1992: 56–63, 183–90 and related discussion in section 3.8.I.

1070. Pliny the Elder, *Natural History* pr.17–18.

1071. Pliny the Elder, *Natural History* 25.5.15–25.6.17.

1072. Pliny the Elder, *Natural History* 2.24.95. Pliny held a very high opinion of Hipparchus and his project (cf. also *Natural History* 2.112.247).

1073. Pliny the Elder, *Natural History* 2.13.62–63.

1074. Pliny the Elder, *Natural History* 2.13.71–2.14.76. Accordingly, omens portending an age of "geniuses and learning" were regarded as auspicious (Pliny the Elder, *Natural History* 2.23.93).

1075. Ptolemy, *Almagest* 1.1 (= Toomer 1984: 37).

1076. Ptolemy, *Almagest* 13.11 (with 3.1, 7.1, and 7.3) = Toomer 1984: 647 (137, 321, 329).

1077. Ptolemy, *Almagest* 4.9 (= Toomer 1984: 206). Similarly, Frontinus, in *Stratagems* 1.pr. (a book serving the very purpose Diodorus had imagined), says he welcomes others improving his work with the addition of more stratagems and examples from history.

1078. Ptolemy, *Analemma* 1 (= Edwards 1984: 79).

1079. Ptolemy, *Geography* 1.2.

1080. Ptolemy, *Geography* 1.7–11 (Ptolemy's situation) and 1.4–6 (example set by Marinus).

1081. Ptolemy, *Geography* 1.5.

1082. For further discussion of Ptolemy's ideas of scientific progress see Cuomo 2001: 183–85.

1083. On Hippocrates' influence in the Roman period: Nutton 2013: 207–21. For sources on Hippocrates and the origins of Hippocratism see Appendix B.

1084. Hippocrates, *On Ancient Medicine* 2.

1085. On this point, alongside more expressions of the value of scientific progress, see Hippocrates, *On Ancient Medicine* 1, 2, 8, 12, 14, etc. Erasistratus thus justified anatomical research by appealing to the Hippocratic ideal of tireless inquiry leading to inevitable progress (cf. Nutton 2013: 136). In contrast, the Empiricist sect consisted of those who stuck to the original Hippocratic injunction against excessive theorizing (cf. Nutton 2013: 145).

1086. Hippocrates, *On the Art of Medicine* 1. Similarly, Diocles (the 'Second Hippocrates') argued that one should trust that new discoveries will be made over time, according to Diocles, *On Health to Pleistarchus*, as quoted in Galen, *On the Powers of Foods* 1.1 (= Kühn 6.456 = Mark Grant 2000: 69). On Diocles as the 'Second Hippocrates' see section 3.2.

1087. Galen, *On the Doctrines of Hippocrates and Plato* 9.1.23–26 (Galen later quotes Hippocrates as saying he had discovered things unknown to his elders: 9.6.49).

1088. Galen, *That the Best Doctor Is Also a Philosopher* 4 (= Kühn 1.63).

1089. Galen, *On the Therapeutic Method* 1.1.7 (quote), 2.6.5 (duty).

1090. Galen, *That the Best Doctor Is Also a Philosopher* 2 (= Kühn 1.57).

1091. For the Christian doctrine, almost identical to Galen's, see Matthew 6:24 and Luke 16:13 ("mammon" was an Aramaic word for wealth, in any form, e.g. money and valuables).

1092. Galen, *On Medical Experience* 10. This is all couched in a convoluted contrafactual rhetorical question, the point of which is that this is Galen's view, and not that of certain of his opponents.

1093. Galen, *An Outline of Empiricism* 7.

1094. Galen, *On the Natural Faculties* 3.10 (= Kühn 2.179–80). Galen even wrote a treatise *On Disagreement in Anatomy* (now lost), explaining why it is that some anatomists disagree with each other in their reported findings (cf. ibid. 3.11 = Kühn 2.182).

1095. Galen, *On Conducting Anatomical Investigations* 1.3 and 2.3 (= Kühn 2.234, 2.289).

1096. Galen, *On Conducting Anatomical Investigations* 1.3 (= Kühn 2.227–28 and 2.232).

1097. Galen, *On Conducting Anatomical Investigations* 7.10 (= Kühn 2.621–22).

1098. Galen, *On the Powers of Foods* 1.1 (= Kühn 6.479–80 = Mark Grant 2000: 78); in mathematical sciences: Galen, On the Affections and Errors of the Soul 2.5 (= Kühn 5.86–87). For these and other examples of Galen's views on scientific progress see Hankinson 1994a (and sources in Hankinson 1991a: 86) and Meissner 1999: 226–45.

1099. Hankinson 1994a: 1779 (cf. 1779–81).

1100. Hankinson 1994a: 1784 (Hankinson also identifies several areas where Galen made scientific progress and then applied those advances to practical effect: 1784–89).

1101. Hankinson 1994b: 1836.

1102. When Galen expresses doubt: For example: Galen, *On the Uses of the Parts* 15.1 (= M.T. May 1968: 658), *On the Affections and Errors of the Soul* 2.7 (= Kühn 5.98–103 = P.N. Singer 1997: 147–49), *On the Doctrines of Hippocrates and Plato* 9.6.20–22.

1103. Galen, *On the Affections and Errors of the Soul* 2.7 (= Kühn 5.98 = P.N. Singer 1997: 147).

1104. Galen held mathematical sciences in regard: See note in chapter 1.2.III.

1105. Galen, *On Medical Experience* 11.

1106. Galen, *On the Function of Respiration* 3 (= Kühn 4.472).

1107. Galen, *On the Therapeutic Method* 12.5 (= Kühn 10.839–40). Galen's tripartite theory (and its connection to his research on respiration) is discussed in Nutton 2013: 238–40.

1108. Furley & Wilkie 1984: 40–69 survey Galen's attempts to improve contemporary Erasistratean theories of circulation and respiration, the errors he made in the process, and how Harvey even more soundly integrated Galenic and Erasistratean theories to develop the first correct theory of circulation (contributing to the eventual discovery of chemical respiration). See also Siegel 1968: 27–134 (circulation) and 135–82 (respiration). It seems arguable that had Galenists and Erasistrateans continued their debate (by refining each other's experiments and research), the discoveries of the 17th century would have been achieved by the 5th.

Section 3.10 Summary & Conclusion

1109. Sambursky 1962: 252.

1110. Lloyd 1973: 174–75 (less coherently echoed in Vernant 1983: 284–85).

1111. What caused the Scientific Revolution: See discussion in chapter 1.1 (and remarks at the end of 3.9.I and 4.7).

1112. That ancient philosophy promoted moral improvement through reason and knowledge (including the scientific), see Trapp 2007, Bryant 1996, and Nussbaum 1994. For Roman examples see the *Moral Epistles* of Seneca and Galen's *On the Affections and Errors of the Soul.*

1113. That "moral improvement could only be achieved through God" and "one ought to embrace instead an austere journey to the next" life. See chapter five, although both propositions are ubiquitously displayed throughout the New Testament, and repeatedly exemplified by later ascetic and monastic movements (cf. e.g. Fox 1987: 293–335).

1114. Embraced scientific values: For Galen see examples in chapter 2.7. For Hero see chapter 4.6.II.

1115. On the example of Artemidorus: For this and the following see discussion in R. White 1975: 1–11 and *EANS* 164, along with Artemidorus, *Interpretation of Dreams* 1.pr and 5.pr.

Chapter Four

Section 4. In Praise of the Scientist

Section 4.1 Philosophers for Science

1116. Galen, *On the Affections and Errors of the Soul* 2.5 (= Kühn 5.92–93). One of the subjects discussed (gravity) was quoted at the end of chapter 3.9.II; another (matter) will be quoted in section 4.6.III below.

1117. That philosophy schools defended science education: In chapter seven of Carrier 2016. For background: *OCD* 657–58 (s.v. "Hellenistic philosophy").

1118. On the rise of eclecticism see discussion and notes in the introduction to chapter 3.7 and Carrier 2016 (index, "eclecticism").

1119. "Philosophies valued the rational and empirical pursuit of the causes of natural phenomena." As implied already here throughout chapters two and three.

1120. Even the Skeptics: See Hankinson 1998 and further discussion in section 4.8.

1121. J. Barnes 1988: 63–67.

1122. In astronomy, for example, Skeptics had no quarrel with the work of Hipparchus (Sextus Empiricus, *Against the Professors* 5.1–2, cf. also 1.50–51 and 5.103–05), and in medicine they supported the Empiricist sect.

1123. Taub 2003: 39–40.

1124. Cicero, *Prior Academics* (= *Lucullus*) 2.41.126–28.

1125. Cicero's philosophy of science: See quotes and examples in chapter 2.5 and 2.6.

1126. Aristotelian philosophy of science: See discussion and scholarship cited in chapters 2.2 and 3.1.

1127. As argued in Aristotle, *Metaphysics* 1.1.980a-1.3.983b (with 2.1.993a and 8.1.1042a).

1128. This is the argument of Aristotle, *Nicomachean Ethics* 10.1.1172a-10.8.1179a. Aristotle also elaborated on all these reasons for pursuing philosophy in his *Exhortation to Philosophy*. Though lost, relevant quotations from this survive in Iamblichus, Protrepticus 6–12.

1129. As shown here, for example, in chapter 3.1 and 3.5 (Galen, Ptolemy, and Hero, for example, though eclectics, all held Aristotelian sympathies).

1130. Cicero, *On the Boundaries of Good and Evil* 4.5.12–13.

1131. Aristotle, *Metaphysics* 8.1.1042a.

1132. For Roman Platonists on these points see Maximus of Tyre, *Orations* 6, 10, 13, and 27 and Alcinous, Epitome of Platonic Doctrine (= Didaskalikos) 3–4 and 7–8 (quoted in chapter 2.5). On Platonist (and Pythagorean) interest in mathematics: Horky 2013.

1133. At least as implied in the judgment of one Roman Platonist: Plutarch, *Pericles* 6.1.

1134. Plutarch, *That Following Epicurus is Unpleasant* 11 (= *Moralia* 1093e-1094d).

1135. Several prominent scientists inspired by Stoic or Epicurean principles are mentioned here in chapters 3.2, 3.3 and 3.4.

1136. Cicero, *On the Boundaries of Good and Evil* 1.19.63–64. Giovacchini 2012 provides the most recent discussion of the quasi-scientific empiricism of Epicureans.

1137. Cicero, *On the Boundaries of Good and Evil* 3.21.72–3.22.73.

1138. M. Clarke 1971: 87–88. For some of the underlying ideas see Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 7.86–89.

1139. Order of teaching subjects: A distinction unfairly mocked as an alleged contradiction in Plutarch, *On the Contradictions of the Stoics* 9 (= Moralia 1035d).

1140. Cicero, *On the Boundaries of Good and Evil* 4.5.11–12.

1141. See related quotes from Cicero in chapter 2.7.

Section 4.2 Literary Praise

1142. With further examples throughout Carrier 2016.

1143. See chapters five and six of Carrier 2016.

1144. Cicero, *On the Orator* 1.17.75–76 (Scaevola), 1.18.80–81 (Antonius).

1145. Cicero, *Tusculan Disputations* 1.19.43–21.49.

1146. Unlike the Christian Origen, who argued it may be better to wait until the afterlife to learn the facts of science (see chapter 5.9).

1147. Cicero, *On the Boundaries of Good and Evil* 5.20.57.

1148. Cicero, *On the Boundaries of Good and Evil* 5.21.58 (in context: 5.18.48–21.60).

1149. Cicero, *On the Boundaries of Good and Evil* 5.19.50–54.

1150. Cicero, *On the Boundaries of Good and Evil* 5.18.48–49 (in context: 5.19.50–54).

1151. Cicero, *On the Nature of the Gods* 2.38.96 (in context: 2.34.87–61.153).

1152. Cicero, *On Divination* 2.28. That aetiology (the study of causes) was widely perceived to be the defining preoccupation of natural philosophy was shown in chapter 2.7.

1153. Virgil, *Georgics* 2.4.90. For the similar pining of Marcus Aurelius see below.

1154. "Science and technology had significant moral value and social utility." See the analysis of J.-M. André 1987 and examples in chapter 3.5.

1155. Columella, *On Agricultural Matters* 1.pr.22.

1156. Pliny the Elder, *Natural History* 2.9.54.

1157. Pliny the Elder, *Natural History* 7.37.123–38.127.

1158. Pliny the Elder, *Natural History* 7.37.125. Chersiphron's Temple of Artemis had become one of the seven wonders of the world. Archimedes is discussed further in sections 4.5 and 4.6.I.

1159. See note on Abdaraxos (and this fragmentary list) in chapter 3.4.

1160. Pliny's fondness for engineering (and its benefits to mankind) is also reflected in his survey of the architectural wonders of the known world, where he includes the pyramids of Egypt and every comparable marvel, yet he concludes it is the sewers of Rome that were *opus omnium dictu maximum*, "the greatest achievement of all," and the aqueducts of Rome that were *vera aestimatione invicta miracula*, "a marvel unsurpassed in value" by anything else ever built: Pliny the Elder, *Natural History* 36.24.104–08 (sewers), 36.24.121–24 (aqueducts).

1161. Plutarch, *How a Man May Become Aware of His Progress in Virtue* 7 (= *Moralia* 78e).

1162. See the end of chapter 2.5.

1163. On Classical Athenian attitudes see note in chapter 1.3. On Socrates' proto-Cynical rejection of natural philosophy (a fact cited by Christians in defense of their own rejection of it) see relevant notes and examples in chapters 5.2 and 5.4 (and in chapter seven of Carrier 2016). For the charges against Socrates and his defense see (and compare) the *Apology* of Plato and the *Apology* of Xenophon.

1164. Plutarch, *On Curiosity* 5 (= *Moralia* 517c-e).

1165. This socially positive view of scientific curiosity, as found in Pliny and Seneca, is surveyed in Beagon 1992: 60–63. For the Christian reversal see chapter five and evidence in P. Harrison 2001 (and in chapter nine of Carrier 2016).

1166. Marcus Aurelius, *Meditations* 7.67.1 (already mentioned in chapter 2.5). His belief that a knowledge of nature increases moral character and control is repeated throughout his *Meditations* (e.g. 2.1, 2.9, 3.11, 4.29, 8.52, 10.9, 11.5, etc.).

1167. Marcus Aurelius, *Meditations* 1.7.1–2 (he struggles with books in 2.2 and 2.3).

1168. Marcus Aurelius, *Meditations* 2.4.

1169. Marcus Aurelius, *Meditations* 1.17.9. Though he might also have had some ideas at odds with a proper study of natural philosophy (as discussed in chapter 3.7.IV).

1170. Marcus Aurelius, *Meditations* 6.47.

1171. Marcus Aurelius, *Meditations* 3.2 (quote comes from the leading point in 3.1).

1172. Marcus Aurelius, *Meditations* 3.2.3.

1173. On this point about ancient art see relevant remarks in chapters 1.1, 3.8.I, and 3.8.IV.

1174. For Galen's attitude see chapter 3.8.I.

1175. Apuleius, *Florida* 18.19–36 (see section 4.5 for his similarly heroic portrayal of the medical theorist Asclepiades). For commentary on this passage: S.J. Harrison 2000: 69–72, 122–25. On this as a popular motivation for discovery and invention in antiquity: Meissner 1999: 89–91 (in the context of a broad survey of many other expressed motives to the same end in ancient literature: 37–122).

1176. Quoting Eusebius, *Preparation for the Gospel* 10.14.10.

1177. For Strato's prestige see chapter 2.5; for Posidonius see chapter 3.3.

1178. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 5.64.

1179. Galen, *On the Natural Faculties* 3.10 (= Kühn 2.178–80).

1180. See Ptolemy, *Harmonics* 3.94.

1181. Ptolemy, *Geography* 1.1.

1182. Argued in Taub 1993: 146–53.

1183. Ptolemy, *Almagest* 1.1.7.

1184. Quoted without attribution in Clement of Alexandria, *Stromata* 4.25:155.1. It is conjectured to derive from the *Antiope* of Euripides (frg. 910) and appears to contain allusions comparing scientific research to the sacred mysteries (cf. Kambitsis 1972: 130–34), a common notion among the pagan elite (see chapter 4.2 and 4.4 and example in chapter 3.5).

1185. From the *Palatine Anthology* 9.577. Compare Eusebius's attitude towards this epigram (quoted and discussed in Carrier 2016: 147–48).

1186. Nutton 2013: 280, 288.

1187. Plutarch, *Questions at a Party* 9.14.3 (= *Moralia* 744c-e).

1188. *OCD* 974 (s.v. "Muses"). They are first named in Hesiod, *Theogony* 76–79 (as the daughters of Zeus and Mnemosyne, the Goddess of Memory: Hesiod, *Theogony* 915–17), but the specific arts each governed are known only from other sources (including Hellenistic and Roman art).

1189. Plutarch, *Questions at a Party* 9.14.3 (= *Moralia* 744e).

1190. Plutarch, *Questions at a Party* 9.14.4 (= *Moralia* 745a). Hephaestus was the Greek god of fire, blacksmiths, and artisans: *OCD* 660–61 (s.v. "Hephaestus"); Vulcan, the closest Roman parallel, had no direct association with craftsmen, only life-threatening fires: *OCD* 1563 (s.v. "Volcanus (Volkanus, Vulcanus)"); Minerva, the Roman goddess of craftsmen, was a third of the Capitoline Triad at Rome, and thus one of the three principal Gods of the City, after Jupiter Optimus Maximus and his wife Juno: *OCD* 957 (s.v. "Minerva"); Minerva's annual festival was a day for honoring all craftsmen (including doctors), who celebrated by marching in a parade: Ovid, *Fasti* 3.809–21, *OCD* 1251 (s.v. "Quinquatrus"), and Graf 2001; Athena, the closest Greek parallel, was also a goddess of craftsmen and technology in her aspect as Athena Erganê ("Athena the Maker"), while in her more general aspect, of course, she was the chief and eponymous goddess of Athens (and by Hephaestus the mother of the first Athenian): *OCD* 194 (s.v. "Athena"), cf. Cuomo 2007: 38–39 and Deacy 2008. For Asclepius and Prometheus see section 4.5.

1191. Plutarch, *Questions at a Party* 9.14.7 (= *Moralia* 746e). Euterpe (a name that means "the well-pleasing") was more traditionally the goddess of the flute. Also identified as patron of advanced knowledge was Hermes (Mercury among the Romans): *OCD* 668–69 and 935 (s.v. "Hermes" and "Mercurius"). Ancient astrologers placed all craftsmen, including doctors, engineers, and astronomers (as well as rhetors, priests, and prophets), under the sign of Mercury: Nutton 2013: 259. This is loosely echoed in Galen, *Exhortation to Study the Arts* 3–5 (= Kühn 1.5–8; compare Philostratus, *Life of Apollonius of Tyana* 8.7.3), who calls Hermes "the lord of reason and every art."

1192. Galen, *On the Uses of the Parts* 7.14 (= M.T. May 1968: 367).

1193. Galen, *On the Uses of the Parts* 17.1 (= M.T. May 1968: 731). On this chapter as a Hymn to God see below. Equations of scientific research with sacred mysteries might connect with an Orphic belief that those who make useful discoveries will go to heaven (e.g. Cicero, *On the Republic* 6.13 and Virgil, *Aeneid* 6.663 and 847–53), on which see Habinek 1989.

1194. Galen, *On the Uses of the Parts* 12.6 (= M.T. May 1968: 558–59).

1195. Galen, *On the Uses of the Parts* 15.1 (= M.T. May 1968: 657–58).

1196. Galen, *On the Uses of the Parts* 7.15 (= M.T. May 1968: 369).

1197. Galen, *On the Uses of the Parts* 10.12 (= M.T. May 1968: 491).

1198. Galen, *On the Uses of the Parts* 3.10 (= M.T. May 1968: 189–91). That this entire book was a worshipful Hymn to God (apart from being obvious here, and throughout its last chapter, and scattered passages elsewhere) is also explained in ibid. 17.3 (= M.T. May 1968: 733).

1199. Galen, *On the Uses of the Parts* 3.10 (= M.T. May 1968: 189–91), cf. also 17.1 (= M.T. May 1968: 730).

1200. Galen, *On the Uses of the Parts* 17.1 (= M.T. May 1968: 730).

1201. Tertullian, *To the Nations* 2.2.

1202. *Codex of Justinian* 9.18.2 (cf. Cuomo 2000: 38–39).

1203. From Ulpian, *All Seats of Judgment* 8 (early 3rd century A.D.), via the *Digest of Justinian* 50.13.1.3.

1204. See, for example, Lloyd 1979, Barton 1994a, Frede & Striker 1996, Schmid 1998, Buxton 1999, and Nutton 2013: 272–78 (who specifically discusses the issue of medical rationalism vs. supernaturalism and superstition in antiquity).

1205. Plutarch, *On Superstition*, which is extant (= *Moralia* 164e-171f); Seneca, *On Superstition*, which is lost (but a sizable quotation, enough to grasp the gist of its argument, appears in Augustine, *City of God* 6.10–11, confirmed by a brief description of the same book in Tertullian, *Apology* 12); Lucretius, *On the Nature of Things* 1.62–135, 5.1161–1240, 6.35–95. A fragment of a lost work on the same subject confirms the same sentiments as these (cf. *P.Oxy*. 2.215).

1206. On the ancient concept of 'superstition' as 'bad religion' built on irrational fear see discussion and sources in *OCD* 1413–14 (s.v. "superstitio") and Janssen 1979, M. Smith 1981, Salzman 1987: 172–75, and Aubrion 1996.

Section 4.3 Evidence of Elite Interest

1207. Dinner parties: Some of these points are demonstrated in Carrier 2016 (index, "lectures"), others here in chapter two.

1208. Educated speakers expected to be science literate: Demonstrated in chapter five of Carrier 2016.

1209. Dio Chrysostom, *Discourses* 33.4–6.

1210. See relevant note on Geminus in chapter 3.3.

1211. On scientific poetry see discussion and notes in chapter four of Carrier 2016. Poets in this genre included Dionysius, Oppian, and (to a lesser extent) Mesomedes (see note on latter two in chapter 3.5). See also section 4.10.

1212. Taub 2003: 138–41. On Lucretius and Roman-era Epicurean poetry see note in chapter 1.2.1. On Manilius see *OCD* 892–93 (s.v. "Manilius, Marcus").

1213. Quote from Cicero, *On the Orator* 3.22.128. On Cicero's unfinished (or partially lost) *Timaeus* see Lévy 2003.

1214. Besides Cicero's (highly interpretive) translation, at least ten commentaries are known to have existed (cf. Runia 1986: 55–57), including one by Galen (Larrain 1992). Further evidence of the popularity of the *Timaeus* is discussed throughout Reydams-Schils 2003.

1215. Gottschalk 1987: 1132.

1216. On this lost poem: Pliny the Elder, *Natural History* 2.22.89.

1217. Plutarch, *On the Face that Appears in the Orb of the Moon* 1–23 (= *Moralia* 920b-937c) constitutes the science portion (the remainder discusses mythology).

1218. Context of Plutarch's *On the Face*: See discussion in Cherniss 1957: 2–8.

1219. For Galen's gatherings see section 4.1. Plutarch's inclusion of a famous contemporary astronomer (Menelaus) may be comparable to Athenaeus's inclusion of a famous contemporary doctor (Galen) among the participants of his (probably) fictional discussion of all things gastronomical in *The Dinnersages* (cf. Nutton 2013: 235).

1220. Rihll 1999: 77.

1221. Cherniss 1957: 18–19.

1222. Plutarch, *On the Face that Appears in the Orb of the Moon* 1 (= *Moralia* 920b).

1223. For scholarship see *DSB* 15.207–08 and 15.222 (in s.v. "Hipparchus") and Schefold 1997: 418–19 and 543 (Abb. 302), and Evans 1999: 297–99, legend reading *HIPPARCHOS NIKAIEÔN*, always with the reigning emperor (bust, name, and titles) on the obverse (with known examples dating from the reign of Antoninus Pius to Gallienus).

1224. Nutton 2013: 212 (with other doctors on Roman coins discussed in Nutton 2013: 261, and see note on the school of Zeuxis in chapter 3.2).

1225. Sextus Aurelius Victor, *On the Caesars* 41.19–21.

1226. Those who attended Galen's lectures: See von Staden 1995: 58 (quoted) and 1997: 36 and 47–49, and Nutton 2013: 230–32, 245.

1227. Galen, *On Conducting Anatomical Investigations* 1.1 (= Kühn 2.215–16).

1228. Galen, *On Conducting Anatomical Investigations* 1.1 (= Kühn 2.218).

1229. Galen, *On Conducting Anatomical Investigations* 7.16 (= Kühn 2.642–43). There are many other examples of such occasions in Galen's writings (e.g. Galen, *On Conducting Anatomical Investigations* 7.16 = Kühn 2.644–46, and see related note in chapter seven of Carrier 2016).

1230. Galen, *On Conducting Anatomical Investigations* 7.10 (= Kühn 2.619–20). See similar examples relating to human dissection in chapter 3.8.III.

1231. Galen, *On Conducting Anatomical Investigations* 4.1 (= Kühn 2.417, 2.420).

1232. Plutarch, *That Following Epicurus is Unpleasant* 13 (= *Moralia* 1095c-1096c); mathematics and astronomy: ibid. 11 = 1093d-1094d.

1233. Apuleius, *Apology* 16.7 (see related note in chapter 3.5).

1234. S.J. Harrison 2000: 56. Examples of similar expectations of significant medical knowledge among laymen are presented in Nutton 2013: 258 (further evidence, for example, in Ballér 1992, Durling 1995, and Renehan 2000). And see discussion and evidence in chapters five through seven of Carrier 2016.

1235. On the continuing use of Greek as the language of the sciences by a bilingual Roman elite see discussion in chapter three of Carrier 2016.

1236. Evidence of rising interest in science: Here in chapter 4.5, and previously in chapters three and ten of Carrier 2016.

1237. On Varro's *Disciplines* see *EANS* 774–78 and discussion in chapter five of Carrier 2016.

1238. On Vitruvius and his encyclopedic standards see discussion and notes in chapter seven of Carrier 2016 (with Vitruvius, *On Architecture* 1.1). There was an earlier Latin writer on the subject of architecture, Publius Septimius (Vitruvius, *On Architecture* 7.pr.14), but little is known of his works.

1239. Quintilian, *Education in Oratory* 12.11.24. His *On Agriculture* filled five volumes and was among the best surveys of the subject according to Columella, *On Agricultural Matters* 1.1.14.

1240. The logic of his transition from agriculture to medicine (as arts that nourish and heal the body) in his preface to the latter might suggest a twelfth and final topic was planned or completed, on philosophy (as the art that nourishes and heals the soul), although other subjects are possible (such as gymnastics or the graphic and plastic arts).

1241. Quality of Celsus: *DSB* 3.174–75, *EANS* 217–19, *OCD* 377, with a handy survey of the debate in Scarborough 1970: 298–302.

1242. Celsus, *On Medicine* pr.1.

1243. On the order and contents of the lost and extant books see scholarship in Taub 2003: 141–42, with 221–22 (notes 60–61 and 66), and Codoñer 1989 and Lausberg 1989.

1244. That he believed he was the first to do this: Pliny the Elder, *Natural History* pr.14.

1245. French & Greenaway 1986: 7.

1246. Healy 1999: 75.

1247. On the merits of Pliny's work see related note in chapter 3.5. Greek encyclopedias existed, though more specialized and sometimes of inferior quality e.g. Aelian's *On the Characteristics of Animals* (3rd century A.D., cf. *EANS* 32–34 and *OCD* 18) and the lost works of Apollonius (and/or Alexander) of Myndus (1st century A.D. or B.C., cf. notes in chapter 3.3 and 3.5).

1248. For example, given Pliny's occupation as a naval commander, books devoted specifically to oceanography, navigation, and seafaring (e.g. ship and naval technology) are conspicuously absent. Similar omissions are suggested by the topics of Seneca's *Natural Questions* and other subjects we know many other authors discussed (cf. chapter 3.5).

1249. Pliny the Elder, *Natural History* 11.2.8.

Section 4.4 Seneca and the Aetna

1250. *DSB* 12.309–10, *EANS* 84–85, *OCD* 92–95 (s.v. "Annaeus Seneca (2)"), and Griffin 1976.

1251. Cf. Seneca, *Natural Questions* 6.1.1 and 7.28.3.

1252. See discussion of Seneca's works in chapter 3.3.

1253. Cf. e.g. Seneca, *Moral Epistles* 20.2 and *Natural Questions* 3.pr.3 and 6.1.1. Regarding his lost *On Earthquakes* see Lausberg 1989: 1926–27. He may also have written a lost work *On the Structure of the Universe* (Lausberg 1989: 1928–29), though other works in natural philosophy attributed to Seneca are less likely to be his.

1254. Seneca, *To Helvia on Consolation* 20.1–2 (further praise of astronomy occupies chapter 8).

1255. See, for example, Taub 2003: 143, 148–51, 159, 161. Extensive analysis of Seneca's justifications for valuing science and natural philosophy (and linking them to moral philosophy) is provided by Chaumartin 2003 and Scott 1999, who confirm the conclusions presented here.

1256. Seneca, *Natural Questions* 3.pr.18.

1257. These are amply demonstrated as themes throughout the *Natural Questions* in Scott 1999.

1258. Seneca, *Natural Questions* 3.pr.3.

1259. Seneca, *Natural Questions* 3.pr.10.

1260. Seneca, *Natural Questions* 1.pr.7.

1261. Seneca, *Natural Questions* 6.3.4.

1262. Seneca, *Natural Questions* 2.59.1–3, that this was the meaning, and originally the end of the treatise, see sources and discussion in Taub 2003: 141–42 and 221–22 (notes 60, 61, and 66).

1263. Seneca, *Natural Questions* 7.1 (cf. also 6.3.2–3).

1264. Seneca, *On Benefits* 5.7. Similarly, Plato saved Dio from fear by teaching him the astronomy of eclipses, according to Plutarch, *Nicias* 23.4. As we'll see in a following section, Cicero and Frontinus told similar stories.

1265. Freedom from fear aspect: See Scott 1999: 60–62.

1266. Seneca, *Natural Questions* 6.4.2.

1267. Seneca, *Natural Questions* 7.1.6.

1268. Seneca, *Natural Questions* 1.pr.1–2 and 1.pr.12.

1269. Seneca, *Moral Epistles* 104.22.

1270. Seneca, *Natural Questions* 3.pr.5–6.

1271. Seneca, *Natural Questions* 3.pr.1.

1272. Seneca, *Natural Questions* 1.pr.12.

1273. Seneca, *Natural Questions* 1.pr.4–5.

1274. Seneca, *Natural Questions* 1.pr.3 (with the whole of 1.pr).

1275. Seneca, *Natural Questions* 6.5.2–3. Seneca draws a lengthier analogy between science and the sacred mysteries in *Moral Epistles* 90.26–29.

1276. Had to repackage it as Christian: On which point see Carrier 2010: 399; and chapter five here.

1277. Seneca, *On Leisure* 4.1–5.8 (= *Dialogues* 8.4.1–8.5.8).

1278. To be as empirical as possible: As argued in Scott 1999: 59 and evident throughout Seneca's treatment of subjects in the *Natural Questions*, in which priority is given to empirical observations when they are available (which for him always trump authorities, armchair logic, or dogmatic requirements).

1279. Seneca, *Moral Letters* 79. Cf. *OCD* 862 (s.v. "Lucilius (2) (Iunior), Gaius"). This Lucilius is also the addressee of Seneca's *Natural Questions* and *On Providence* (= *Dialogues* 1). Though Seneca's letters are literary creations (generally composed after-the-fact), the events and communications they refer to are probably genuine (cf. D. Russell 1974, with Griffin 1976: 3–6, 349–50, 416–19). In this case, for example, Seneca and Lucilius could already have exchanged correspondence on this matter years before, which Seneca then conveyed and summarized in this literary creation (quite possibly after the publication of the *Aetna*, a poem discussed below).

1280. Pliny the Younger, *Letters* 4.30 (this spring was briefly mentioned by his uncle: Pliny the Elder, *Natural History* 2.106.232) and (for ghosts and poltergeists) 7.27. On Sura see *OCD* 835 (s.v. "Licinius Sura, Lucius").

1281. Seneca, *Moral Letters* 79.1–7. For those curious, Charybdis (now dubbed Gerofalo) is technically real; it manifests sometimes as a small (and thus quite harmless) maelstrom in the Strait of Messina (between Sicily and Italy), caused by the *real* danger to navigation there: unnaturally strong tidal currents, which can rapidly pull ships into unexpected courses (Bignami & Salusti 1990). And Hephaestion is a real place: natural gas burns from the ground at Yanartash (modern "Burningstone," in the province of Lycia, now Turkey), which in antiquity was named after a nearby temple to Hephaestus (the gods' blacksmith).

1282. *OCD* 30 (s.v. "*Aetna*" and "Aetna (1)") and *EANS* 39. For an accessible introduction, Latin edition, and English translation of the *Aetna* see Duff & Duff 1935: 351–419. For the most recent scholarship on the *Aetna*'s authorship and date see W. Richter 1963: 1–8, Paisley & Oldroyd 1979, and Goodyear 1984; and on its content and purpose, Taub 2008: 30–55. For critical editions of the Latin text (with commentary) see W. Richter 1963 and Goodyear 1965. Regarding its date, some note the *Aetna* also does not mention an earthquake that struck Pompeii in 63 A.D., but there is no reason to expect that a poem on volcanoes would mention an earthquake that, at the time, was not linked to volcanic activity.

1283. *Aetna* 144–45.

1284. *Aetna* 222–29.

1285. *Aetna* 229–47.

1286. *Aetna* 248–51.

1287. *Aetna* 252–57.

1288. *Aetna* 258–73.

1289. *Aetna* 274–82.

1290. *Aetna* 282–95 (blending into the rest of the poem, which explores many of these questions).

Section 4.5 The Scientist as Hero in the Roman Era

1291. Anti-scientism in modern fiction: For example, see Crouch 1975 and Lougee 1972.

1292. Doctors critiqued only for being bad scientists: As noted in chapter 3.8.I.

1293. See references on ancient astrology in Carrier 2016: 109, n. 285.

1294. See *OCD* 180–81 (s.v. "Asclepius"); Edelstein & Edelstein 1945; Hart 2000; and Nutton 2013: 104–12, 162–64, 282–90.

1295. Notably, certain Jewish sectarians who later influenced the Christians reversed this sentiment, replacing Prometheus with the Watchers, fallen angels in league with Satan, portraying their bringing to humanity knowledge and technology as an evil deed and a betrayal of God that ruined the world: Portier-Young 2014.

1296. Hesiod, *Theogony* 506–616; Pausanias, *Description of Greece* 1.30.2, 2.19.5–8, 5.11.6, 9.25.6, 10.4.4; [Pseudo-?]Aeschylus, *Prometheus Bound* (esp. lines 442–525; this was part of a trilogy, with *Prometheus Unbound* and *Prometheus Firebringer* extant only in fragments); etc. Modern scholarship: *OCD* 1217 (s.v. "Prometheus") with Lovejoy & Boas 1935: 200–03, Edelstein 1967: 6–7 and 43, Vernant 1983: 237–48, Kreitzer 1994: 11–49, Podlecki 2005: 15–16, Dougherty 2006, and Calame 2010.

1297. See *OCD* 409–10 (s.v. "Daedalus") and Frontisi-Ducroux 2000. It is sometimes forgotten today that it was only his son, Icarus, who flew too close to the sun and thus melted his manmade wings and fell to his doom. Daedalus himself successfully completed the flight. Moderns similarly tend to forget that the Titanic's sister ship, the Olympic, was breached many times but never sank, and her other sister ship, the Britannic, was only sunk by a mine in WWI after being pressed into military service. Our selective memory tells us more about us than the ancients.

1298. Ritti et al. 2007.

1299. The only extant version of her story appears in the Roman author Hyginus, *Fabulous Stories* 274.10–13. See King 1986, von Staden 1989: 38–41, and *EANS* 354 and *OCD* 39–40 (s.v. "Agnodice"), with Irby-Massie 1993: 364–67.

1300. Pliny the Elder, *Natural History* 18.68.272–274.

1301. A similar sacrifice of wealth to study astronomy is told of Anaxagoras: Diogenes Laertius, Lives and Opinions of Eminent Philosophers 2.7.

1302. Thales legend: Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 1.26; Cicero, *On Divination* 1.49.111–50.112; and at the earliest: Aristotle, *Politics* 1.11.1259a (who is already aware of its legendary nature, correctly noting that it is too ridiculous to be true). A number of other heroic legends accumulated around Thales (cf. Dicks 1959).

1303. Cf. *OCD* 1358 (s.v. "Sextius, Quintus"), Capitani 1991, and Griffin 1976: 37–42. Celsus the encyclopedist is also thought to have been a pupil.

1304. Legends of the Presocratics: For example: Cicero, *On Divination* 1.50.112 and 2.13.30–32; Pliny the Elder, *Natural History* 2.59.149 and 7.37.123; Plutarch, *Pericles* 6; Maximus of Tyre, *Orations* 13.5; Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 1.116; Philostratus, Life of Apollonius of Tyana 1.2; Ammianus Marcellinus, *Deeds of the Divine Caesars* 22.16.22; Iamblichus, *Life of Pythagoras* 136; etc.

1305. Pliny the Elder, *Natural History* 2.81.191–92. See my related discussion of Pliny's high hopes for natural philosophy in chapter 3.8.I.

1306. Cicero reports that the Pherecydes-earthquake myth was commonly taught in Roman-era schools (despite it being, Cicero is quick to note, unbelievable): Carrier 2016: 77.

1307. Asclepiades was discussed in chapters 2.3 and 3.2; Archimedes in chapter 3.4.

1308. Pliny the Elder, *Natural History* 7.37.124 (cf. also 26.8.15).

1309. Pliny the Elder, *Natural History* 26.7.12–9.20. Galen likewise criticized Asclepiades and his pupils, even more harshly, but again on grounds of methodology and scientific merit.

1310. Apuleius, *Florida* 19. For commentary see S.J. Harrison 2000: 125–26.

1311. See Pliny the Elder, *Natural History* 2.9.53–55, with *OCD* 1412 (s.v. "Sulpicius Gallus, Gaius"), Rawson 1985: 162, and Bowen 2002 (though Bowen provides a useful survey of the evidence, his conclusions are undermined by a flawed treatment of both the chronological problems and the sources, e.g. he ignores the Antikythera computer as evidence of eclipse prediction as a going concern of the 2nd century B.C., and assumes modern computer calculations of solstice dates correspond to ancient identifications of solstitial days).

1312. Cicero, *On Old Age* 14.49.

1313. Cicero, *On the Republic* 1.15.23–24.

1314. On the symbolic use of science in dispelling a fear of eclipses see section 4.4. For an attempt by the emperor Claudius to use such a tactic on a grander scale see Carrier 2016: 133–35.

1315. Valerius Maximus, *Memorable Deeds and Sayings* 8.11.1, which recounts essentially the same story in Cicero, as also in Pliny the Elder, *Natural History* 2.9.53–55; Frontinus, *Stratagems* 1.12.8; and Quintilian, *Education in Oratory* 1.10.47.

1316. Livy, *From the Founding of the City* 44.37 and Zonaras, *Epitome of History* 2.316–17 (paraphrasing a lost section of Cassius Dio, *Roman History* 20).

1317. Plutarch, *Aemilius Paulus* 17.7–12. On the competing strategies of exploiting the superstitions of one's troops vs. teaching them science instead, see Carrier 2016: 83.

1318. Thales: e.g. Herodotus, *History* 1.74. Agathocles and Pericles: e.g. Cicero, *On the Republic* 1.16.25; Plutarch, *Pericles* 35.2 and *Nicias* 23; Frontinus, *Stratagems* 1.12.9–10; Quintilian, *Education in Oratory* 1.10.46–48; Valerius Maximus, *Memorable Deeds and Sayings* 8.9.ext.2.

1319. For examples of this praise of Archimedes see chapter 3.9.II and sections 4.2 above and 4.6.I below. For scholarship and a summary of his life and achievements see chapter 3.4 (with related discussion of his orreries and armillary spheres in chapter 3.3).

1320. In Cicero's account of his own 'heroic' discovery of the lost tomb of Archimedes: Cicero, *Tusculan Disputations* 5.23.64–66 (discussed in Carrier 2016: 135, n. 373; and: Simms 1990, Cuomo 2001: 197–98, and Jaeger 2002).

1321. Silius Italicus, *Punic Wars* 14.338–53 (following his account of the ingenious weaponry deployed against the Romans: 292–337). Note that Silius's reference to Archimedes counting the sands of the earth is a deliberate allusion to *The Sandreckoner*, in which Archimedes more or less does exactly that. Possibly Silius's other statements also allude to books of Archimedes known at the time but now lost. There are many extant accounts of Archimedes' mechanical defenses of Syracuse: e.g. Polybius, Histories 8.3–7, Livy, From the Founding of the City 24.33–34, and Plutarch, *Marcellus* 14–17. Polyaenus, *Stratagems* 8.11.1 merely mentions the fact, while the accounts in Cassius Dio, *Roman History* 15 and Diodorus Siculus, *Historical Library* 26.18 are lost, though more or less paraphrased in John Tzetzes, *Book of Ages* 2.103–49 and Zonaras, *Epitome of History* 9.4–5 (= 2.262–65).

1322. Valerius Maximus, *Memorable Deeds and Sayings* 8.7.ext.7.

1323. Various accounts of Archimedes' death are given in some of the accounts of the siege of Syracuse (see earlier note) and also in: Cicero, *On the Boundaries of Good and Evil* 5.19.50, *Against Verres* 2.4.58.131, and *Tusculan Disputations* 5.23.64–66; Livy, From the Founding of the City 25.31; Pliny the Elder, *Natural History* 7.37.125; Plutarch, *Marcellus* 19. On a mosaic depicting it (though a suspected forgery) see chapter 1.3.

1324. Roman elite praising Archimedes: For example: Cicero, *Tusculan Disputations* 2.61; Pliny the Elder, *Natural History* 7.30.112; Plutarch, *Pompey* 42; cf. Rawson 1985: 106, Kidd 1988: 22–30 and 1999: 38–41, and (more cynically) P. Green 1990: 642–43. On Posidonius see chapter 3.3.

1325. Vitruvius, *On Architecture* 9.pr.9–12, abbreviated in Plutarch, *That Following Epicurus is Unpleasant* 11 (= *Moralia* 1094c).

1326. Vitruvius, *On Architecture* 9.pr.1–3. Other quasi-heroic feats attributed to Archimedes are discussed in Russo 1996: 25–26 and Simms 1991, 1995, and 2005. Plutarch, in *Marcellus* 16.3 and 17.1–4 relates how Marcellus and his soldiers also regarded his achievements in military engineering to be godlike and heroic in scale. That those who do anything of benefit to mankind should be deified as a reward is also suggested in Pliny the Elder, *Natural History* 2.5.18 (since "for mortal to aid mortal, that is God, and the path to eternal glory"). Accordingly, some engineers considered their skills divine: R. Taylor 2003: 10 and Tybjerg 2003: 457–62.

1327. Datus inscription: *CIL* 8.2728 (= *ILS* 5795). Translation and discussion in Cuomo 2001: 158–59 and Cuomo 2011. For the broader context of similar inscriptions by builders and engineers see Kolb 2015. Though we can't be sure of his ethnicity, it is notable that Datus is an African name; so his story may belong to black history as well as the history of science (Cuomo 2011: 158–59).

1328. Pliny as hero and naturalist: All evidenced in chapter 3.8.I and 3.9.II and in sections 4.2 and 4.3 above. Pliny the Younger was also (eventually) his uncle's son by adoption: *OCD* 1162–63 (s.v. "Pliny (2) the Younger").

1329. Pliny the Younger, *Letters* 6.16.1–12 (written c. 106 A.D.). The word for 'hero' in the text (at 6.16.9) is *maximo*, "in greatness," i.e. heroically. Contrast this heroic narrative with how the first generation of Christians (didn't) write about Jesus: Carrier 2014a: 510–28.

1330. Pliny the Younger, *Letters* 6.16.17 and 6.16.20. Pliny says he included in this letter every detail he witnessed himself or heard immediately afterward "when reports were most likely to be accurate" (6.16.22), then gives an account of what happened to himself in *Letters* 6.20.

1331. Purpose of history: See chapter 3.9.II. That Tacitus agreed with Diodorus on the function of historical writing is explicit in Tacitus, *Agricola* 1.1 and *Annals* 3.65.

1332. On Demostratus see note in chapter 3.5.

1333. Aelian, *On the Characteristics of Animals* 13.21. It is hard to discern what is from Demostratus and what from Aelian here, but I take the peculiar clause *hôs ekeinos legei* ("as Demostratus says") as indicating the rest of that sentence is from Aelian, and no longer a direct quote of Demostratus (as I have indicated with punctuation accordingly). The same 'Triton of Tanagra' is also discussed in Pausanias, *Description of Greece* 9.20.4–9.21.1, though with no mention of these events.

1334. Lucian, *Alexander the Quack Prophet* 55–58. Similarly, devoted followers of the physician Thessalus allegedly plotted to assassinate Galen (cf. Iskandar 1988: 154 §P.60,12), and members of the Sanhedrin to assassinate Paul (Acts 23:12–35), in each case for skeptically criticizing what could be described as a popular religious business enterprise.

1335. Role of scientific values in religion: A fact also explored in chapter 2.6.

Section 4.6 The Scientist as Craftsman in the Roman Era

1336. Snobbery: Farrington 1946: 28 (cf. Cohen 1994: 248). This remains a standard view on ancient attitudes towards craftsmen: *OCD* 178 (s.v. "artisans and craftsmen").

1337. No change in aristocratic attitude: See discussion in chapter 1.1.

1338. P. Green 1990: 481 and Finley 1981: 180. Also argued by others, e.g. Zilsel 1945: 328–29; Sambursky 1962: 257–70; etc.

1339. P. Green 1990: 482.

1340. P. Green 1990: 471.

1341. Beckmann et al. 1846: 2.97 (n. 1). The first edition was published by Beckmann in 1797, Beckmann died in 1811, and his work was translated and updated several times after that by additional contributors, but this note remains his.

1342. Pliny the Elder, *Natural History* pr.12–16 (discussed below) and Columella, *On Agricultural Matters* 1.pr.10–29 (discussed in chapter 3.9.II).

1343. Oxford comment: Arnander 2007.

1344. Xenophon, *Economics* 4.2–3. The word *banausos* (and its cognates) derives from *baunos*, "furnace, forge" and thus denoted workmen associated with furnace work, and then by association all similarly crippling shopwork (cf. *LSG* 305, s.v. "*banausia*," "*banausikos*," "*banausos*," etc. and *LSG* 311, s.v. "*baunos*").

1345. Pseudo-Aristotle, *Economics* 1.2.1343b.

1346. Aristotle, *Politics* 7.14.1333a.

1347. Aristotle, *Politics* 8.2.1337b.

1348. Aristotle, *Parts of Animals* 1.5.645a.

1349. Aristotle, *Politics* 8.5.1339b. His defense of music occupies 8.3.1338a-8.5.1341b.

1350. As explicitly stated, for example, in Aristotle, *Politics* 3.4.1277b. See my related discussions in chapters 3.5 and 3.7.I.

1351. Aristotle, *Nicomachean Ethics* 4.2.1123a. Compare my discussion of the related attitudes of Isocrates and subsequent authors in chapter five of Carrier 2016.

1352. As implied in Plato, *Gorgias* 512b-e (which attests a diversity of opinions regarding craftsmen among the aristocracy of Classical Athens, ranging from snobbery to appreciation).

1353. Aristotle, *Metaphysics* 1.1.981a-b.

1354. *Palatine Anthology* 11.326.

1355. *Palatine Anthology* 12.237. Hence note the advice on respectable vs. inappropriate ways of procuring pay and employment in Vitruvius, *On Architecture* 6.pr.4–6.

1356. Cicero, *On Duties* 1.42.151. The key passage here reads: *artibus aut prudentia maior inest aut non mediocris utilitas quaeritur (ut medicina ut architectura ut doctrina rerum honestarum) eae sunt iis quorum ordini conueniunt honestae*. The latter phrase literally reads "these [professions] are for those to whose honorable rank [such professions] are suited."

1357. Cicero, *On Duties* 1.42.150.

1358. The key sentence reads: *opificesque omnes in sordida arte uersantur nec enim quicquam ingenuum habere potest officina*. An *opifex* is anyone who makes things professionally, and an *officina* anywhere such manufacturing is done.

1359. Cicero, *Brutus* 73.255–257.

1360. For example: Galen, *On the Therapeutic Method* 1.1 vs. *Exhortation to Study the Arts* 5–9 (= Kühn 1.7–22). On this point see commentary in Hankinson 1991a: 85–86.

1361. Galen, *Exhortation to Study the Arts* 13 (= Kühn 1.32–33). An even higher opinion of agricultural labor (and laborers) is expressed in Musonius Rufus, *Sermons* 11, and though this was by no means a universal sentiment, it was not uncommon (cf. Xenophon above).

1362. Pliny the Elder, *Natural History* pr.12–14.

1363. Pliny the Elder, *Natural History* pr.15 (*abunde pulchrum atque magnificum*) and pr.16.

1364. Marcus Aurelius, *Meditations* 3.2 (discussed in section 4.2).

1365. Plutarch, *Whether Land or Sea Animals are Cleverer* 11 (= *Moralia* 968a-b).

1366. Cf. *LSG* 196 (s.v. "*apodechomai*"): "accept," "accept advice from," "accept as a teacher," "follow," "admit to one's presence," "admit to the mind," "receive favorably," "approve," "accept the statement or story that," "receive or accept from," "believe or agree with," "acknowledge," "understand."

1367. Plutarch, *Marcellus* 14.7–12.

1368. Plutarch, *Marcellus* 17.5–7.

1369. See sources on Eudoxus in Appendix B. For Eratosthenes' inscription about (and invention of) the mesolabe see sources in the relevant note in chapter 3.5.

1370. *On the Method of Mechanical Theorems*: See discussion in chapter 3.8.IV.

1371. In his inscription celebrating the mesolabe's invention (see relevant note in chapter 3.5).

1372. Plutarch, *Marcellus* 14.12–13. See chapter 3.4 for the actual development of mechanics.

1373. Plutarch, *Marcellus* 15–16.

1374. See note on armillary spheres in chapter 3.3.

1375. Plutarch, *Marcellus* 19.11–12.

1376. That a lot of war technology was not published due to concerns of national security (to ensure a competitive edge against state enemies) is soundly argued in Russo 2003: 198–99 (cf. also 110, 114–16, 137–38, 165 and Tybjerg 2004: 44–46) and attested as actual policy at Rhodes, Cyzicus, and Marseilles (Strabo, *Geography* 14.2.5). In addition, Simms 1995: 67–68 shows that by all reliable accounts nothing Archimedes employed militarily was of novel invention (thus he might have written nothing because he designed nothing); although Rihll suggests the opposite, that Archimedes' lost treatises or teachings on the subject influenced those of Philo of Byzantium (Rihll 2007: 122). Though one should perhaps add that, the competing views of Simms and Rihll aside, Archimedes might have written on his defenses of Syracuse had he survived the siege.

1377. Evidence Archimedes wrote books on machines: See section 4.5, discussion in chapter 3.4, example in chapter 3.9.II, and relevant notes in chapter 3.6. The more nuanced claim was made by Carpus of Antioch, a Roman-era astronomer, mathematician, and engineer (see chapter 3.4), according to Pappus, *Mathematical Collection* 8.3.1026, who nevertheless could not recall exactly where Carpus had said it.

1378. Vitruvius, *On Architecture* 7.pr.14 (cf. also 1.1.17).

1379. Simms 1995: 71–96, Authier 1995, Cuomo 2001: 192–211, and Russo 2003: 198 all identify reasons to reject Plutarch's account as in almost every respect the exact reverse of the truth. That ancient mathematicians *in general* were very pro-instrument and practical (proving Plutarch's view unusual) is demonstrated in Cuomo 2000: 83, 91–109 and Cuomo 2001 *passim*.

1380. Maximus of Tyre, *Orations* 37.7.

1381. Cicero, *Tusculan Disputations* 1.2.5.

1382. P. Green 1990: 850–51, n. 33 (cf. also 458 and 465).

1383. On Seneca's assault on modern technology see chapter 3.8.I.

1384. Seneca, *Moral Epistles* 90.31–33.

1385. Seneca, *Moral Epistles* 90.13.

1386. Seneca, *Moral Epistles* 88.1–2 (against money-seeking professions), 88.18–19 (against luxury professions), 88.20 (quoted remark). It should be noted that all such railing against money-making pursuits is mostly for show: the elite

(Seneca included) routinely pursued profits through often massive enterprises in trade and industry and even the much-maligned usury. They relied on trusted intermediaries of lower status to manage their commercial and industrial assets and banking contracts, but there is no reason to believe they were in any way aloof to how their business managers were disposing of their capital investments. This is extensively discussed in D'Arms 1981. See also sources on ancient economic attitudes and realities in the introduction to chapter 3.6.

1387. On Seneca, *Moral Epistles* 88, see the commentaries of Stückelberger 1965 and Kidd 1978. On the content of the liberal arts, see chapter five of Carrier 2016 (as noted there, these arts sometimes included gymnastics and drawing—as even Seneca attests in 88.18, though he opposes their inclusion).

1388. Seneca, *Moral Epistles* 88.36–37 (in context: 88.33–36): *quod ista liberalium artium consectatio molestos, verbosos, intempestivos, sibi placentes facit et ideo non discentes necessaria, quia supervacua didicerunt*. Seneca offers a similar attack on the aimless pursuit of trivia (in the context of accumulating libraries) in *On Tranquility* 9.5 (= *Dialogues* 9.9.5). Galen also attacks the boorishness of 'trivia hounds' who avoid a serious pursuit of the sciences, in Galen, *On Examinations by Which the Best Physicians Are Recognized* 13.2–3.

1389. Seneca, *Moral Epistles* 88.45.

1390. Seneca, *Moral Epistles* 88.3–8 (grammar), 88.9 (music), 88.10–13 (geometry and arithmetic), 88.14–17 (astronomy).

1391. Seneca, *Natural Questions* 1.5.13.

1392. Stückelberger 1965: 54: *die Überwindung der wissenschaftlich forschenden Haltung der Mittelstoa durch ein streng moralisches Denken*.

1393. Stückelberger 1965: 79. As demonstrated in chapter 3.9.II and section 4.4 above, there can be no doubt what Seneca really felt about scientific research.

1394. Seneca, *Natural Questions* 6.32.1–2.

1395. Stoics were actually more passionate about logic and science than ethical theory: Carrier 2016: 102–04.

1396. From Edelstein 1952: 579–85, to K.D. White 1993, to Rihll & Tucker 2002 and Cuomo 2007.

1397. Scholarship on the Roman social system is extensive, but for a summary supporting the following assessment see Atkins & Osborne 2006: 4–11, MacMullen 1974, and Garnsey 1970, with a particular focus on the elite in Mratschek-Halfmann 1993. J. Clarke 2003: 4–9 provides a useful discussion of the application of class terminology to the Roman period, but expanding on his scheme, I position the middle class as straddling Clarke's binary demarcation between elite and non-elite.

1398. For discussion of the social status of artisans and the values unique to their class see Burford 1972: 185–218 (and throughout) and Cuomo 2007 (with also Cuomo 2011: 159). J. Clarke 2003 likewise finds evidence in extant art of the difference in values with respect to work between the Roman 'aristocracy' and the lower and middle classes, a conclusion supported by the epigraphic analysis of Joshel 1992.

1399. Lucian's example: I discuss this in chapter ten of Carrier 2016.

1400. Lucian, *On the Dream* or *Lucian's Career* 1 (his family recommended *tina technên tôn banausôn toutôn ekmathoimi*, "that he be educated in some art of the banausic variety") and yet 2 (this art still had to be *andri eleutherô prepousa*, "appropriate for a free man," hence being a stoneworker was judged to be such).

1401. Lucian, *On the Dream* or *Lucian's Career* 3–5 (in 12 he notes that even Socrates was a stoneworker, cf. Diogenes Laertius, *Lives and Opinions of Eminent Philosophers* 2.5.18–21).

1402. Lucian, *On the Dream* or *Lucian's Career* 6–18.

1403. "It would be an improvement in social position." As argued for the medical profession in Nutton 2013: 261–71 and Horstmanshoff 1990: 187–96; the same would hold true for engineers and astrologers (there would also be the same distinctions within such trades, in levels of education and accomplishment, as held for doctors).

1404. Rihll 2002: 20.

1405. A summary of what we know of Vitruvius and a summary and bibliography on what we know of Galen are both available in Carrier 2016: 111–19.

1406. Pliny represents an upper middle class attitude: As argued, for example, in Syme 1969: 219–25. On Pliny the Elder's life and career see *DSB* 11.38–40, *NDSB* 6.116–21, *EANS* 671–72, *OCD* 1162, Syme 1969, French & Greenaway 1986: 1–10, and Beagon 1992: 1–25. For a discussion of his research habits, and a list of his writings (almost all lost), see Pliny the Younger, *Letters* 3.5.

1407. Beagon 1992: 5 and 6 (cf. 5–11).

1408. Social status of doctors and engineers: See relevant notes and remarks in chapter 1.3.

1409. In addition to the works cited in chapter 1.3, the situation is summarized in Rawson 1985: 84–86 (for doctors) and 86–88 (for architects and engineers).

1410. Nutton 2013: 257–71. Most of the examples he considers from lower levels of society would not have been scientifically educated doctors, much less engaged in scientific research, so actual 'scientists' should be counted among the higher ranking end of the curve.

1411. Nutton 2013: 243. For example: Galen, *Exhortation to Study the Arts* 5–9 (= Kühn 1.7–22).

1412. Cuomo 2001: 169–75.

1413. Cuomo 2001: 161–68.

1414. Hero, *Mechanics* 1.20–23 and 2.32. The Arabic text of his *Baroulkos* (in *Mechanics* 1.1) also shows he included a calculation for expected friction in its design (cf. Drachmann 1963: 22–32). Hero also discussed the stress limits of machinery. See Schneider 1992: 212–15.

1415. Drachmann 1963: 49. See Schiefsky 2008.

1416. Dividing labor and theory: A development identified and attacked by Vesalius in the preface to his work *On the Fabric of the Human Body* (first published in 1543).

1417. Farrington 1946: 29.

1418. Farrington 1946: 34.

1419. See Cuomo 2001: 201–05 and my discussion of developments in ancient scientific method introducing chapter 3.7 and concluding chapter 3.1.

1420. Vitruvius, *On Architecture* 1.1.2 (within the whole context of 1.1).

1421. Celsus, *On Medicine* pr.39. See related discussion in chapter seven of Carrier 2016.

1422. Columella, *On Agricultural Matters* 1.1.16–17 (he then surveys examples of needed areas of research and experimentation in 1.pr.22–28).

1423. Tybjerg 2005. Tybjerg 2003: 446–51 further argues that Hero uses this and other tactics to argue against those still clinging to anti-banausic attitudes (though our analysis in 4.6.1 already qualifies the degree and popularity of such attitudes).

1424. Tybjerg 2005: 213–18 (quote from 215); Hero, *Pneumatics* 2.4–7 (see related discussion in chapter 2.7). See also Tybjerg 2003: 451–57 and 446–51.

1425. Galen argues same point from all the sciences: See chapter 3.6.VI (and related discussion in chapter 3.9.II and sections 4.1 above and 4.6.III below).

1426. Practical and theory must combine: For Galen see Nutton 2013: 237 and relevant discussion and notes below.

1427. Tybjerg 2003: 455.

1428. "Galen's emphasis on visible progress and the superiority of empirical and practical knowledge." See, for example, von Staden 1995.

1429. "To prove by example that empirical research makes progress in philosophy where arguments only stagnate." Confirming the analysis concluding chapter 3.9.II.

1430. Galen, *On the Uses of the Parts* 2.3 (= M.T. May 1968: 118–19).

1431. Galen, *On Conducting Anatomical Investigations* 1.3 (= Kühn 2.233–34). C.J. Singer 1956: 8 translates Galen as saying he was "avoiding the task myself as beneath my dignity" but neither the word 'beneath' nor 'dignity' is in the text, which reads: *men oun k'âimoi tôn hupêretôn tis exedere tous pithêkous, oknounti dêlonoti kai mikroteron ê kat' eme nomizonti t'ourgon*, "And so I too had one of my assistants skin the apes, which is to say I avoided it and thought the work too trivial for me to do," i.e. he though it was not worth the trouble, not that it was undignified.

1432. Aristotle, *On the Parts of Animals* 1.5.645a.

1433. See Nutton 2013: 243.

1434. Mark Grant 2000: 11.

1435. Craftsmen must have worked with scientists on projects: As argued, for example, in Di Pasquale 2002.

1436. Craftsmen must have worked with scientists on instruments: See evidence in chapter 3.6.

1437. *OCD* 188–89 (s.v. "astronomical instruments"); and see examples in chapters 3.3 and 3.6.

1438. See Cuomo 2001: 153–55, Dilke 1971: 71–73, and Di Pasquale 2002.

1439. Nutton 1995: 10–13 (and throughout).

1440. French 1994: 238–39 and 252–53. See chapter 3.1 for Aristotle and 3.5 for Theophrastus.

1441. Pliny the Elder, *Natural History* 34.18.45–47.

1442. Seneca, *Natural Questions* 3.7.1 and 86.14–21.

1443. Galen, *That the Best Doctor Is Also a Philosopher* 3 (= Kühn 1.58–59).

1444. Nutton 2013: 251–52.

1445. Nutton 2013: 223. See Galen, *Commentary on Hippocrates' Airs, Waters, Places*.

1446. Nutton 2000a: 962.

1447. Mark Grant 2000: 12.

1448. Elephant: Galen, *On Conducting Anatomical Investigations* 7.10 (= Kühn 2.620). It is not literally a bone that is meant but a bony tissue (cf. Kühn 2.618–19), since more specific tissue identification was not possible in antiquity without a microscope. Notably, Galen's 'colleague' was not a slave but *tina tôn gegumnasmenôn hetairôn*, "one of my educated friends," i.e. a social equal of Galen, who evidently had more experience dealing with kitchen staff. Grain osmosis: Galen, *On the Natural Faculties* 1.14 (= Kühn 2.55–56), discussed at the end of chapter 3.2.

1449. Plutarch, *Antony* 28. See Scarborough 2012: 10–14.

1450. Frontinus, *On the Aqueducts of Rome* 1–2. Of his 'other' treatises only two are known (but not extant), his *Art of War* and one or more books on the science of surveying (some fragments of which survive). On this man and his extant writings see the end of chapter 3.4.

1451. Athenaeus, *The Dinnersages* 1.13c (citing prose treatises by Seleucus of Tarsus, Agathocles of Atrax, and Leonidas of Byzantium, about whom little or nothing is now known). See also chapter 3.5 and, to a lesser extent, Corcoran 1964 (though his generalizations about Roman interests are obsolete or untenable and his sourcing is poor).

1452. Humphrey et al. 1998: 579–99 vs. Edelstein 1967: xiv-xv (which, ironically, they cite in their bibliography).

1453. Humphrey et al. 1998: 587.

1454. Lucian's example: See chapter ten of Carrier 2016 and chapter 4.6.II here.

1455. Humphrey et al. 1998: 593 (Frontinus), 589–90 (Archimedes), 594–95 (Seneca), 595 (Tiberius and Vespasian, though their treatment of the latter is better than most).

1456. Humphrey et al. 1998: 583–84, quoting Aristotle, *Politics* 1.4.1258b-59.

1457. *LSG* 1952 (s.v. "*phortikos*"): 1. "of the nature of a burden, tiresome, wearisome, onerous" and only after that 2. "coarse, vulgar, common, low."

1458. Humphrey et al. 1998: 579–80.

1459. Hesiod, *Works and Days* 303–11, 410–13.

1460. That the need of labor was a sign of social decline: Hesiod, *Works and Days* 174–77.

1461. Hesiod, *Works and Days* 455–57 (repeating a proverb to the effect that the rich and presumptuous do not know what is involved in constructing a wagon).

1462. Homer, *Odyssey* 17.382–86.

1463. Oleson at least may have revised his views (judging from, e.g., Oleson 2004) and has overseen the production of a far more sophisticated *Oxford Handbook of Engineering and Technology in the Classical World* (Oleson 2008).

1464. Galen, *On the Affections and Errors of the Soul* 2.7 (= Kühn 5.99–100). Translation adapted from P.N. Singer 1997: 147–48. The method the engineer explained must have involved the hydrostatics of Archimedes and Menelaus (the only practical way to compare weights by volumes: e.g. weigh the wood on a scale, then immerse the wood in water and then weigh on a scale the water it displaces, and their weights by equal volume will be determined).

Section 4.7 Lack of Institutional Support?

1465. Scientists not pooling resources: See discussion in Edelstein 1952: 596–602.

1466. See chapter 8 of Carrier 2016, which also covers every point to follow, including the role of libraries, science clubs, and the equivalent of universities in the Roman era. To which should be added Houston 2014 (on libraries).

1467. Plato, *Republic* 7.528b-e (of math and astronomy, but implies also harmonics at 7.530d-e).

1468. Xenophon, *Hiero* 9.7–11. Although this is not the same point as made in Aristotle, *Politics* 2.8.1268a, who says the architect Hippodamus, as part of his ideal constitution, "proposed a law that those who discovered anything of advantage to the state should receive honors," for a little later Aristotle makes quite clear that technologies were not meant (nor even advances in the arts), but the exposure of secrets and conspiracies and the proposing of new laws.

1469. Philo of Byzantium, *Siegecraft* 4.1–5 (= Marsden 1971: 107–09 = DeVoto 1996: 5–9). Zilsel's claim that Philo was "not a scholar but a military engineer," a sort who "were never admitted as fellows to the Alexandrian Museum," is simply and entirely false (Zilsel 1945: 328–29).

1470. On rapid advances in naval war technology in this period see Foley & Soedel 1981 (with scholarship cited in the notes on naval technology in chapter 3.6.III and 3.8.IV).

1471. Diodorus Siculus, *Historical Library* 14.41.1–43.4. See discussion in Rihll 2007: 26–30 and D. Campbell 2011.

1472. Pliny the Elder, *Natural History* 2.6.43.

1473. Pliny the Elder, *Natural History* 8.17.44.

1474. It is still debated (see, for example, Healy 1999: 72–73).

1475. Vitruvius, *On Architecture* 9.pr.1–2. This is similar to Aristotle, *Rhetoric* 3.14.2.1414b, which says "Isocrates disparaged the Athenians because they rewarded bodily excellences, but instituted no prize for men of wisdom" (i.e. Isocrates, *Panegyric* 1, though in *Panegyric* 45 he says Athens *did* have prize-winning contests in "eloquence and wisdom and all the other arts").

1476. Vitruvius, *On Architecture* 9.pr.3–17.

1477. Finley 1985: 146.

1478. Consider the remarks of Meissner 1999: 25–28, 450.

1479. On what could have caused a scientific revolution: All this I have already suggested and discussed in chapter 3.6.VI, 3.9.I, and 3.10.

1480. Pseudo-Aristotle, *Problems* 30.11.

1481. On this ideal of historical glory see discussion of Diodorus in chapter 3.9.II and Apuleius in chapter 4.2 and examples in chapter 4.5. On salaries and pensions see chapter 3.1.

1482. Vitruvius, *On Architecture* 6.pr.1–3; Galen, *Exhortation to Study the Arts* 5 (= Kühn 1.8–9).

1483. Edelstein 1963: 27, 28.

1484. Edelstein 1952: 598–99.

Section 4.8 Evidence of Non-Christian Hostility to Science

1485. Likewise indications of indifference amidst praise documented throughout Carrier 2016.

1486. Widespread scientific illiteracy and superstition: For example see: Quintus Curtius Rufus, *History of Alexander* 4.10.1–7; Seneca, *Natural Questions* 7.1.2; Tacitus, *Annals* 1.28.

1487. See also Carrier 2016: 100. Adding to the resources cited there: Bett 2011 and *OCD* 1324–25 (s.v. "Sceptics").

1488. Sextus Empiricus, *Against the Natural Philosophers* 1.12–194 (whether anything can be said about the existence and nature of any gods), 1.195–2.351 (whether anything can be said about the metaphysics of causation, the structure of matter, the nature of space, motion, time, abstract numbers, and the metaphysics of generation and decay), almost all of which consists (in practice) of disputing semantics rather than pragmatic beliefs.

1489. Sextus Empiricus, *Against the Natural Philosophers* 2.66–69 and 2.168, with *Outlines of Pyrrhonism* 1.236–41. On this allowance of science as a pragmatic acceptance of the appearances see the analysis of J. Barnes 1988.

1490. See Breebaart 1976 and Toynbee 1944. These were also exceptional events. Domitian expelled philosophers not just from Rome but from the whole of Italy (according to Suetonius, *Domitian* 10 and Aulus Gellius, *Attic Nights* 15.11.3–5), but this is listed among his criminal acts (which were abolished by the Senate after his death, cf. *OCD* 411, s.v. "*damnatio memoriae*"). Suetonius does not mention Vespasian having done anything like this, and even implies the contrary (Suetonius, *Vespasian* 13–15). We hear only a confused account from John Xiphilin's epitome (of Cassius Dio, *Roman History* 66.13) that moral and political agitation by certain Cynic and Stoic philosophers led Vespasian to expel "all the philosophers," but the context of the occasion suggests only certain philosophers were meant (e.g. "all the [offending] philosophers" not "all philosophers"). This is supported by Gellius, who lists Domitian's act as the only occasion of such a general expulsion under an emperor.

1491. *Lives of Aesop*, vita g § 35 (= e cod. 397 bibliothecae pierponti morgan, recensio 3). See discussion of this work in chapter 2.8.

1492. In case it is not obvious, the social visibility of astronomers would result from, among other things, their production of public sundials (cf. Cuomo 2001: 151–153) and *parapegmata*, astronomically-based agricultural calendars erected and maintained in most ancient towns and cities for the benefit of farmers and merchants (cf. Taub 2003: 20–37, 41–43, 173–76; Lehoux 2007b; Hannah 2009: 49–49). Meanwhile the visible products of doctors and engineers is more than obvious.

Section 4.9 The Path to Christian Values

1493. Josephus, *Jewish Antiquities* 12.12.99. For the original context, see the earliest version still extant in (Pseudo?)-Aristaeus, *Letter to Philocrates* 187–292 (which includes too much detail to be in any doubt about the subject of discussion).

1494. Philo of Alexandria, *On the Special Laws* 1.336.

1495. Philo of Alexandria, *On the Virtues* 8.

1496. Ben-Dov & Sanders 2014; Newmyer 1996.

1497. See discussion and evidence in Carrier 2016: 141–43.

1498. Philo, *That Every Good Man Is Free* 12.80.

1499. Eusebius, *Preparation for the Gospel* 8.12.9.

1500. Gregory Thaumaturgus, *Panegyric Oration on Origen* 8. There is some dispute as to the actual identity of the author, but his identity is supported by Eusebius (*History of the Church* 6.30), who was using Origen's library at the time and thus would be in a good position to know, while arguments against the attribution are not very persuasive. Whatever his name, the author was certainly a student of Origen writing in the middle of the 3rd century. See Trigg 1998: 36–37 and 249 (n. 6); and Crouzel 1979 and 1969; with *OCD* 636 (s.v. "Gregory (4) Thaumaturgus") and *ODCC* 713–14 (s.v. "Gregory Thaumaturgus, St.").

1501. See Carrier 2016: 149–55; and related discussion in chapter 5.9 here.

1502. Eusebius, *Preparation for the Gospel* 11.7.

1503. *Infancy Gospel of Thomas* 6:1–8:2, which contains a detailed account of this classroom nightmare that is astonishing to read. In fact, this entire Gospel reads like a proposed screenplay for *The Omen* that the studio rejected because it was too scary.

1504. *Arabic Gospel of the Infancy of the Savior* 50–53 (greatly expanding on Luke 2:42–47), quoting the English translation of Roberts & Donaldson 1896. The extant Greek text (cf. 19:1–5) does not expand on this passage from Luke anywhere near this extensively nor in the same way, but there is evidence the Arabic text might be closer to the original Greek text (cf. Klauck 2003: 73–78 and Schneemelcher & Wilson 1991: 1.414–69).

Section 4.10 Summary & Conclusion

1505. Ben-David 1984: 42.

1506. Rawson 1985: 282.

1507. Rawson 1985: 284–85.

1508. See Rawson 1985: 289–91 and Gottschalk 1987 (who rightly explains that Aristotle's works were never actually 'lost' as Roman legends liked to claim, though there was a revival of interest in them, and a new critical edition was produced).

1509. Quote from Greene 1994: 25.

Chapter Five

Section 5. Christian Rejection of the Scientist

1510. Christian use of natural philosophers to defend theology: Bynum 1995: 19–58.

1511. Clagett 1955: 118–29.

1512. Clagett 1955: 146–82.

1513. Clagett 1955: 120, 130.

1514. Clagett 1955: 133.

1515. Clagett 1955: 130–45, in which he further documents that Christian attitudes toward science and natural philosophy were never very positive. R.M. Grant 1952: 87–126 provides a representative survey of the poor quality of scientific knowledge in early Christian writers, the often unscientific way in which such knowledge was used, and their generally hostile attitude toward scientific values (and though he cites Christian sources in adequate abundance, his assessment of the state of Roman science on p. 120 is unsourced and wholly incorrect—he clearly could not have read the works of Galen, Hero, or Ptolemy).

1516. The idea of philosophy as the "handmaiden" (i.e. slave) to theology and faith actually derives (word and all) from the Jewish philosopher Philo of Alexandria in the 1st century A.D. (see chapter 4.8 here and chapter nine of Carrier 2016), only later picked up by Christian intellectuals like Clement of Alexandria (Clagett 1955: 134–35). See related note in section 5.6.III below.

1517. Quote of de Ste. Croix: In Crombie 1963: 87 (with: 79–87).

1518. Thessalus: Kudlien 1970: 24–25.

1519. "Quite the reverse of scientific reasoning." On this kind of thinking throughout antiquity see Dodds 1951.

1520. Lloyd 1973: 167 (examples of the prevalence of this Christian hostility: 167–71).

1521. Lloyd 1973: 169–171.

1522. On this "flipping" of epistemic values upside down, see discussions in Walzer 1949.

1523. This adds to several other examples of Christian attitudes already discussed in chapters 2.6, 3.8.IV, and 4.8 here, and chapter nine of Carrier 2016, which supplement the evidence in the present chapter.

Section 5.1 Clement of Alexandria (c. 200 A.D.)

1524. For background on Clement of Alexandria see *OCD* 331 (s.v. "Clement of Alexandria (Titus Flavius Clemens)") and *ODCC* 364–65 (s.v. "Clement of Alexandria").

1525. Clement of Alexandria, *Stromata* 6.10:80.5–81.1 and 1.9:43.1.

1526. Clement of Alexandria, *Stromata* 6.8:66.1.

1527. Clement of Alexandria, *Stromata* 1.9:43.4.

1528. Clement of Alexandria, *Stromata* 1.9:44.3.

1529. See Clement of Alexandria, *Stromata* 1.10.

1530. Clement of Alexandria, *Stromata* 1.11:50.1–50.3 (quoting 1 Corinthians 3:18–20).

1531. Clement of Alexandria, *Stromata* 1.11:51.4–52.3. His anchor quotes come from Colossians 2. I'll discuss later where he is getting this material from in the Bible.

1532. Clement further explains the limited uses of philosophy in *Stromata* 1.17 and 1.20.

1533. Clement of Alexandria, *Stromata* 1.11:53.2 and 51.2.

1534. Clement of Alexandria, *Stromata* 1.18:88.4–88.8.

1535. Clement of Alexandria, *Stromata* 1.18:90.1–90.2. What Clement considers to be "true philosophy" is scriptural truth, as articulated in *Stromata* 6.7 and 6.8.

1536. Clement of Alexandria, *Stromata* 6.8:62.1 ("true knowledge," *gnôsis*, is only attained by receiving and understanding prophetic scripture, as Clement argued in *Stromata* 6.7).

1537. Clement of Alexandria, *Stromata* 6.8:62.3–62.4 and 6.8:68.1.

1538. Clement of Alexandria, *Stromata* 6.10:80.1–80.2.

1539. Clement of Alexandria, *Stromata* 6.10:80.3–80.4 (referencing the same legend in Philo that Abraham began an astronomer and ended a man of God: see discussion in chapter 4.8 here and Carrier 2016: 142).

1540. Clement of Alexandria, *Stromata* 6.10:82.4–83.1. On the "curriculum of studies" (here *mathêseis tas egkuklious*) see chapter five of Carrier 2016. For philosophy as a mere "preparatory" study that is largely obsolete, and entirely subservient to theology, see Clement of Alexandria, *Stromata* 1.5.

1541. Clement of Alexandria, *Stromata* 6.18:166.4–166.5 (concluding the point argued throughout 6.18).

1542. Clement of Alexandria, *Stromata* 8.1:1.1–1.2 (possibly part of a separate lost work on logic).

1543. Clement of Alexandria, *Stromata* 8.1:2.1–2.2.

1544. Clement of Alexandria, *Stromata* 8.1:2.4–2.5.

1545. Clement of Alexandria, *Stromata* 1.19:93.1–93.4, citing Plato, *Lovers* 137b (also known as *Demodicus*) and *Republic* 5.475d-e. In retreating from empiricism into mystical armchair speculation, Clement's 'Christianized' philosophy was moving in very much the same direction as pagan Neoplatonism, at nearly the same time (and notably both dominated the world after the 3rd century, Christendom winning out only by being the more ruthless): cf. Remes 2008 with *OCD* 1007, and 722, 1163–64, 1190–91 (s.v. "Neoplatonism," and "Iamblichus (2)," "Plotinus," and "Porphyry").

1546. Clement of Alexandria, *Stromata* 2.4:14.1–15.1. Clement here paraphrases and 'interprets' the Biblical Jesus, who says to his disciples: "Do not be called 'Rabbi', for one is your Teacher (*didaskalos*) and you are all brothers; nor call [anyone] on earth your father, for one is your Father: the one in heaven; nor be called tutor (*kathêgêtês*), because one is your Tutor: Christ" (Matthew 23:8–10).

1547. Clement of Alexandria, *Stromata* 2.4:13.3–13.4. On defining 'nature' see chapter 2.1–2.2.

1548. Clement of Alexandria, *Stromata* 2.4:17.4 (quoting Isaiah 7:9), faith is declared "the infallible criterion" in 2.4:12.1. See analysis in Osborn 2005: 155–212.

1549. Clement of Alexandria, *Stromata* 2.4:16.1. Clement's epistemology is the whole subject of *Stromata* 2.4 (and furthered in 2.11), which throughout argues the role of obedience in the order of knowledge: first believe, then you will know. Clement also draws on Hebrews 11 here, which we will discuss in section 5.6. For his complete discussion of faith as a method and source of knowledge see *Stromata* 2.1–2.4 and 5.1.

1550. Argued in Clement of Alexandria, *Stromata* 4.1. Also compare his statement that he will 'next' show what sort of natural philosopher a Christian should be (*Stromata* 6.18:168.4), and the content of what actually follows (*Stromata* 7).

Section 5.2 Tertullian (c. 200 A.D.)

1551. For background on Tertullian see *OCD* 1444–45 (s.v. "Tertullian (Quintus Septimius Florens Tertullianus)") and *ODCC* 1591–92 (s.v. "Tertullian, Quintus Septimius Florens").

1552. Tertullian, *To the Nations* 2.4.47.

1553. Tertullian, *To the Nations* 2.4.47.

1554. Pagan attitude toward the Thales legend: Articulated at length in Plato, *Theaetetus* 173e-176a (more briefly in Diogenes Laertius, Lives and Opinions of Eminent Philosophers 1.34).

1555. Tertullian, *To the Nations* 2.4.47.

1556. Tertullian, *To the Nations* 2.1.41.

1557. Tertullian, *To the Nations* 2.2.42.

1558. Tertullian, *To the Nations* 2.2.42.

1559. Tertullian, *To the Nations* 2.6.50.

1560. Tertullian, *To the Nations* 2.6.50.

1561. Tertullian, *To the Nations* 2.5.48–49.

1562. Tertullian, *Against Marcion* 1.13. For more evidence of this view see chapter 2.5.

1563. Tertullian, *To the Nations* 2.2. For more evidence of this view see chapter 2.6.

1564. Quotes and paraphrases from Tertullian, *Apology* 46.

1565. From Tertullian, *Apology* 46.

1566. Tertullian, *Prescription against Heretics* 7.

1567. Ibid., using the words *curiositas* (curiosity) and *inquisitio* (research; more precisely, "critical inquiry").

1568. Tertullian, *Prescription against Heretics* 11–14 (in fact, because Church doctrine comes from God, everything that disagrees with Church doctrine is by definition false: 21–28).

1569. Quotation from Tertullian, *On the Soul* 1 (first line) and 2 (remainder).

1570. von Staden 1989: 142; Lloyd 1973: 76.

1571. Crouzel 1989: 156.

1572. von Staden 1989: 143. This idea originates with Socrates (see relevant notes and discussion in chapter 4.2 and section 5.4 here, and Carrier 2016: 100–01), but was rejected by every subsequent school of thought except the Cynics (who were socially uninfluential) and the Christians (who only became influential after the decline of the empire).

1573. Tieleman 1996 establishes the latter as a treatise using empirical and experimental science to answer fundamental questions about the nature of the soul.

1574. Tertullian, *On the Soul* 1–4, 7, 26 (scripture is authoritative); 5–6, 8, 10–25, 27–58 (armchair reasoning); 9 (visions received by a church lady counted as evidence).

Section 5.3 Lactantius (c. 300 A.D.)

1575. For background on Lactantius see *OCD* 789 (s.v. "Lactantius (Lucius Caelius (Caecilius?) Firmianus also called Lactantius)") and *ODCC* 942 (s.v. "Lactantius"). For another example of his attitude, which supports and informs the following, see Carrier 2016: 160–63.

1576. Lactantius, *Divine Institutes* 3.8.25.

1577. Lactantius, *Divine Institutes* 3.8.27.

1578. Lactantius, *Divine Institutes* 3.8.29–30.

1579. Lactantius, *Divine Institutes* 3.30.8.

1580. Lactantius, *Divine Institutes* 3.5.1–2.

1581. Lactantius, *Divine Institutes* 3.5.4.

1582. Lactantius, *Divine Institutes* 3.3.1 and 3.4.2 (united by the argument of 3.3–4).

1583. Lactantius, *Divine Institutes* 3.4.1.

1584. Lactantius, *Divine Institutes* 3.3.4–7.

1585. Lactantius, *Divine Institutes* 3.3.7–15.

1586. Lactantius, *Divine Institutes* 3.6.1.

1587. From Lactantius, *Divine Institutes* 7.1.11, 7.2.9, and 7.2.11 (in the context of the whole of 7.1–2 the sentiment is clearly meant to be universalized to all doctrines about nature) and 7.2.9 and 7.2.11 (here again universalized; see also the arguments of 1.1, 3.1, 3.30, and 6.18.1). Hence Lactantius outlines a Christian 'version' of natural philosophy in 7.3–14, supposedly based on scripture though in fact almost entirely conjecturing from fundamental Christian dogmas (which he elaborates in his separate work *On the Craftsmanship of God*), while in 7.15–26 he lays out what scripture supposedly proves about the coming end of the world.

1588. Lactantius, *Divine Institutes* 3.6.5 and 3.6.9. On Arcesilas and the Middle Academy see *OCD* 2 and 136 (s.v. "Academy" and "Arcesilaus (1) or Arcesilas").

1589. Lactantius, *Divine Institutes* 3.6.16–17. This is a sentiment extending all the way into Jewish literature (e.g. 1 Enoch), whereby knowledge not revealed by God is meant not to be known; and thus when revealed, must be demonic.

1590. Lactantius, *Epitome of the Divine Institutes* 30.6 (= 35.6 in a variant *numeration): using inanis, "empty, groundless, worthless, inane," and inutilis, "useless, unprofitable, harmful." This epitome was written by Lactantius himself, as explained in its preface.*

1591. Lactantius, *Divine Institutes* 3.6.20.

1592. Lactantius, *Divine Institutes* 3.10.9.

1593. Lactantius, *Divine Institutes* 3.10.12–15.

1594. Lactantius, *Divine Institutes* 3.24.

1595. Lactantius, *Divine Institutes* 3.24.1 (as the full context of 3.24 makes clear, Lactantius did not even accept that the heavens revolved beneath the earth).

1596. That many ignorant people insisted the earth must surely be flat (and some for the same reasons as Lactantius) is attested in Pliny the Elder, *Natural History* 2.65.161.

1597. That educated people knew multiple evidences the earth was round: Aristotle, *On the Heavens* 2.14.297a-298a; Strabo, *Geography* 1.1.20; Pliny the Elder, *Natural History* 2.65.161–166 and 2.71.177–77.187; Cleomedes' *On the Heavens* 1.5; Theon of Smyrna, *Aspects of Mathematics Useful for Reading Plato* 3.1.120–4.124; Ptolemy, *Almagest* 1.4; plus various passages throughout Ptolemy's *Geography* and Geminus' *Introduction to Astronomy*.

Section 5.4 Eusebius (c. 300 A.D.)

1598. For background on Eusebius see *OCD* 555–56 (s.v. "Eusebius") and *ODCC* 574 (s.v. id.).

1599. Everything good about pagan philosophy actually stolen from the scriptures: The same argument was previously made by Tertullian (*To the Nations* 2.2, *Apology* 47, *Testimony of the Soul* 5) and Clement of Alexandria (*Stromata* 1.15, 1.17, 2.5, 2.18, 5.14, 6.3).

1600. Carriker 2003 surveys the known contents of Origen's library available to Eusebius.

1601. Eusebius, *Preparation for the Gospel* 8.12.9, quoting Philo, *That Every Good Man Is Free* 12(80). See also chapter 4.9 and Philo, *On Agriculture* 16 and *On the Changing of Names* 74.

1602. Jewish attitude that walked a fine line: As discussed in chapter 4.9 here and chapter nine of Carrier 2016.

1603. Eusebius, *Preparation for the Gospel* 14.16.11. See also chapter 2.6 here.

1604. Eusebius, *Preparation for the Gospel* 14.10.7.

1605. Eusebius, *Preparation for the Gospel* 14.10.11.

1606. Eusebius, *Preparation for the Gospel* 15.1.10.

1607. Eusebius, *Preparation for the Gospel* 1.pr.1 (and also 1.8.1). Lactantius deployed the same argument, in *Divine Institutes* 1.1, 3.1, 3.4, 5.3, etc., and *Epitome* 32 (= 27). Likewise the Christian author Hermias, who may be a predecessor to Eusebius (or an incompetent successor), composed the mediocre but viciously hostile *Mockery of the Profane Philosophers*, satirizing pagan disagreements on questions of natural philosophy (dated variously from the 2nd to the 6th century A.D.): cf. *OCD* 670 (s.v. "Hermias (3)") and *ODCC* 761 (s.v. "Hermias").

1608. Eusebius, *Preparation for the Gospel* 14.2.7 (cf. 14.3.6).

1609. Eusebius, *Preparation for the Gospel* 14.13.9 (repeated in 15.61.11, etc.).

1610. Eusebius, *Preparation for the Gospel* 14.13.9 (quoting Plato, *The Republic* 530e-531c); Eusebius, *Preparation for the Gospel* 1.8.14–19 (quoting Plato, *Phaedo* 96a and Xenophon, *Memorabilia* 1.1.11–13). On Socrates see related notes in section 5.2 and chapter 4.2 here and in Carrier 2016 (index, "Socrates").

1611. This is the argument of Eusebius, *Preparation for the Gospel* 14.10–11 (eventually quoting Xenophon, *Memorabilia* 4.7).

1612. Eusebius, *Preparation for the Gospel* 15.61.11. This is the argument of the entire fifteenth book of his *Preparation for the Gospel* (cf. 15.1 and 15.61–62), which surveys a wide array of questions in science and natural philosophy (including astronomy, meteorology, and human physiology), and declares them all void of any value or solution.

1613. Eusebius, *Preparation for the Gospel* 14.9.4.

1614. See, for example: Eusebius, *Preparation for the Gospel* 11.7 and 14.10.

1615. Eusebius, *Preparation for the Gospel* 15.62.7–8.

1616. Eusebius, *Preparation for the Gospel* 15.62.8–9.

1617. Eusebius, *Preparation for the Gospel* 1.8.13.

1618. Eusebius, *Preparation for the Gospel* 14.14.7; cf. also 15.62.

1619. Eusebius, *Preparation for the Gospel* 15.62.11–15.

1620. Eusebius, *Preparation for the Gospel* 15.62.9–10.

Section 5.5 Christian Anti-Intellectualism?

1621. See Hofstadter 1962, Pigliucci 2002, Noll 2008, Jacoby 2008, and Pierce 2010.

1622. See Alexander 2002; with chapters nine and ten of Carrier 2016.

1623. Jost et al. 2003. Hunsberger & Altemeyer 2006 present evidence and scholarship on the association of these personality traits with modern conservative Christianity.

1624. Fox 1987: 330–33. The clearest examples of this sentiment are voiced in Justin Martyr, *Dialogue of Justin and Trypho the Jew* 2–8; Tatian, *Address to the Greeks* 29–30; and Theophilus, *To Autolycus* 1.14.

1625. Ptolemy, *Tetrabiblos* 1.1.2–3. For Galen see Carrier 2016: 161–63 (where I also show that Lactantius confirms the same observation).

1626. Gregory Thaumaturgus, *Panegyric Oration on Origen* 13. On the identity of this Gregory see note in chapter 4.9. For discussion of Origen's attitude and its consequences see section 5.9 (and related discussions in chapter 4.8 here, and Carrier 2016: 150–54).

Section 5.6 Evidence in the New Testament

1627. Scriptural origins of anti-scientism: This connection with scripture is most explicit, for example, in Clement of Alexandria, *Stromata* 1.11, where many of the following passages are quoted or paraphrased.

1628. Upstanding behavior or suffering as proof of sincerity: For examples of the latter see 2 Corinthians 11:23–33, 12:7–10, and for a good discussion see Barnett 1997: 534–77. For context and background on Paul the Apostle see *OCD* 1095–96 (s.v. "Paul, St.") and *ODCC* 1234–38 (id.).

1629. 2 Corinthians 12:12 and 1 Thessalonians 1:5.

1630. Hebrews 2:3–4.

1631. Acts calls the miracles performed by Jesus "powers and marvels and signs" (Acts 2:22) and also calls the miracles performed by the Apostles "marvels and signs" (Acts 2:43, 4:30, 5:12, 14:3, 15:12) and "powers" (Acts 8:13, 19:11), but when it's the apostles, these are generally quite mundane, e.g. inspired babbling (e.g. Acts 2:1–18, 2:33, 10:44–48), escapes from prisons (e.g. Acts 12:6–11; 16:23–30), and demonic exorcism and psychosomatic healing (e.g. Acts 3:1–16, 4:9–17, 8:6–7, 14:8–11), i.e. always curing only 'demonic possession', blindness, and paralysis, which have known psychological causes and cures (e.g. Shorter 1992; note even the alleged psychosomatic *causing* of blindness in 9:8–18 and 13:11–12), never any demonstrably real biological ailment like wounds, tumors, diarrhea or vomiting, or lost limbs or organs.

1632. Congregational miracles: 1 Corinthians 12:8–10 (for useful discussion see Fee 1987: 590–99).

1633. Power meaning exorcism: This might be implied in Ephesians 1:19–22 and 3:7–12, and is suggested by Mark 16:17 (cf. Acts 19:13–17; Luke 10:17) and Justin Martyr, *Dialogue of Justin and Trypho the Jew* 30. The same ambiguous phrase appears again in Galatians 3:5.

1634. Immunity to poisons: Mark 16:17–18 (see extensive discussion in Kelhoffer 2000); e.g. Acts 28:3–6 depicts Paul's expected immunity to snake venom.

1635. 1 Corinthians 14. References to "speaking in tongues" and to "prophesying" as an ongoing phenomenon in the Church (and as a proof of the Gospel's truth) can be found throughout the New Testament: Mark 16:17; Acts 2:3–4, 2:11, 10:46, 19:6; 1 Corinthians 12:28, 12:30, 13:1–2, 13:8, 14:1–28; and: Romans 12:6; 1 Thessalonians 5:20; Acts 21:9; 1 Corinthians 11:4–5, 13:9. The phenomenon is discussed in Fee 1987: 652–713. Prophesy was also associated with dreams, visions, and "revelations" (Acts 2:17–18; 1 Corinthians 14:26–33; 2 Corinthians 12:1; Revelation 10:11). The power of prophecy was thought to be conferred on converts by elders through the "laying on of hands" (1 Timothy 4:14; 2 Timothy 1:6; Acts 8:18, 19:6). For the entire range of schizotypal behaviors revered within the early churches and their known scientific background see Carrier 2014a: 124–37.

1636. Telling the difference between the influence of good and evil spirits: As suggested in 1 Thessalonians 5:21; 1 John 4:1–5:13; 2 Peter 1:19–2:22; Matthew 7:15–20, 24:11–12, 24:23–29.

1637. A method of extracting hidden claims in the scriptures invented by the Jews and called *pesher*: Carrier 2014a: 87–88.

1638. 1 Corinthians 15:3–4 (emphasis added). See also Carrier 2014a: 137–43.

1639. Acts 8:27–39 and 17:11–12 (see commentary in Bruce 1988: 173–79, 326–28).

1640. Romans 16:25–26 (emphasis added); the same point is made in Ephesians 3:3–11 (a forgery that nevertheless represents what the winning faction of Christianity wanted Paul to have said); e.g. Acts depicts Paul "confounding" his opponents with his interpretations of scripture (Acts 18:28).

1641. Romans 15:4 and 1 Corinthians 4:6.

1642. 2 Peter 1:19–21.

1643. 2 Timothy 3:14–16.

1644. 1 Corinthians 12:8 and Romans 16:25–26.

1645. 1 Corinthians 15:3–4 and following note.

1646. Galatians 1:11–12 and 1:15–16.

1647. Ephesians 3:3 (written by someone passing themselves off as Paul).

1648. For example, Paul refers to "the outstanding quality of the revelations" God granted him (2 Corinthians 12:7), including an actual mystical conversation he had with Jesus (2 Corinthians 12:8–9); he made journeys "according to revelation" (Gal. 2:2; cf. Acts 13:2); hints at a specific example (2 Corinthians 12:1–10, cf. Barnett 1997: 556–77); and occasionally distinguished between his own opinions and instructions from God (1 Cor. 7:12, 7:25 vs. 14:37).

1649. Ephesians 3:5.

1650. Ephesians 1:16–18.

1651. Eusebius, *Preparation for the Gospel* 11.7 (see also section 5.4 above).

1652. 1 Corinthians 2:6–13. Discussed in Fee 1987: 97–120.

1653. Acts 7:55–56, 10:1–7, 11:5–14, 12:6–11, 16:9–10, 22:17–21; see also 2 Corinthians 12:1–5 and, of course, the entire book of Revelation. Outside the New Testament, *Diognetus* 11–12 also articulates the nature and superiority of this 'holy spirit' epistemology (and cf., e.g., Lactantius, *Divine Institutes* 3.6; Tatian, *Address to the Greeks* 27; etc.).

1654. Matthew says Christ alone is our *didaskalos* (teacher, master, chorus trainer) and *kathêgêtês* (guide, tutor, professor) according to Matthew 23:8–10.

1655. 1 Corinthians 2:15–16.

1656. Stark 2001: 9–29; Malina 2001: 1–13, 129–31; Malina & Pilch 2000: 1–24, 41–44; Malina & Neyrey 1996: 212–18. See also: Pilch 2002; Segal 2004; Fales 1996a, 1996b, 1999. Further discussion relating to the early Christian context: Malina & Rohrbaugh 2003: 140, 369, 398–99 and 1998: 282–85. Further discussion relating to the pagan context: Dodds 1951: 64–101, 102–34; Fox 1987: 102–67; P. Green 1990: 408–13, 594–95; I.M. Lewis 2003.

1657. 1 Corinthians 2:1–5.

1658. 2 Timothy 2:7.

1659. All useful information will come to you through divine inspiration: Mark 13:11; Luke 12:11–12, 21:13–15. On how this translated into the Christian view of education in general see chapter nine of Carrier 2016. On Quintilian's opposite view see chapters five and six therein. For the consequences of this, as played out between Galen and Lactantius, see chapter ten therein.

1660. 2 Corinthians 5:7 and 4:18, with relevant commentary in Barnett 1997: 245–77 (the context here is evidence that the brethren are aging and dying, which we are to discount in favor of the 'unseen' evidence that they will live again: see Carrier 2005b: 125, 139–41).

1661. 1 John 2:27.

1662. This is the entire argument of Hebrews 11, that "faith" (*pistis*), faith in Scripture and the gospel, is their "evidence" (*hupostasis*, *elegchos*), which they will be rewarded for (hence the context: Hebrews 10:19–39), cf. Bruce 1990: 276–331; and Carrier 2009: 236–40.

1663. 1 Corinthians 14:6.

1664. Moral test: This is implied in Galatians 1:6–17; 1 Thessalonians 5:19–22; 1 Timothy 6:3–4, 6:20–21; 1 John 4:1–5:13; 2 Peter 1:19–2:22; and in Matthew 7:15–20 and 24:11–12, 24:23–29; James 3:13–4:17; 2 Thessalonians 2:1–12; 1 Timothy 4:1–7; 1 John 4:4–6. In contrast, Paul essentially condemns philosophical 'reasoning' (see section 5.6.II below).

1665. 1 Corinthians 12:28. See also Romans 12:6–8 and Ephesians 4:11.

1666. For further analysis of early Christian epistemology see Carrier 2009, chs. 7, 13, and 17.

1667. Carrier 2010: 408. For example: Hebrews 1:10–12; 1 Corinthians 1:28, 6:13, 7:31; and passages cited below.

1668. 2 Peter 3:10–13.

1669. 1 John 2:15–17.

1670. 1 Corinthians 7:29–31.

1671. James 4:4.

1672. Galatians 4:3, 4:8–9 and 6:14, and Colossians 2:8 and 2:20 (though the latter written by Pseudo-Paul), with relevant discussion in Fung 1988: 306–07 and Dunn 1996: 145–51, who also note that early Christians linked the natural elements (e.g. 2 Peter 3:10–12) with the governance of demons (e.g. Justin Martyr, *Apology* 2.5).

1673. Colossians 3:2.

1674. Philippians 3:8.

1675. Colossians 2:8. For the context of this hostility in Paul and Pseudo-Paul see Judge 1983.

1676. In part because the elements were believed to be operating under the control of demonic forces: Carrier 2014a: 180–93. For some discussion of these and other passages from the epistles hostile to philosophical inquiry see Judge 1983: 11–14.

1677. 1 Corinthians 2:14. A similar sentiment is voiced in 1 John 4:4–6; likewise, Jesus is made to have said: "I praise you, o father, lord of heaven and earth, that you did hide these things from the wise (*sophoi*) and intelligent (*synetoi*) and revealed them to children (*nêpioi*)" (Matthew 11:25; Luke 10:21).

1678. 1 Corinthians 1:19–27 (perhaps loosely quoting Isaiah 29:14; cf. Fee 1987: 66–88): *sophos*, "wise man," essentially means philosopher, while *suzêtêtês*, "coinvestigator," means one who debates and discusses questions and theories with others, with the aim of discovering the truth (which often included appeals to evidence and scientific argument), or who conducts research with others (hence also describing scientific collaboration), cf. *LSG* 1670 (s.v. "*suzêteô*," "*suzêtêsis*," "*suzêtêtês*," "*suzêtêtikos*").

1679. 1 Corinthians 3:18–20 (cf. Fee 1987: 150–56). Paul's second quote comes from the Septuagint text of Psalms 94:11 (though he notably replaces *anthrôpôn*, "men," with the more specific *sophôn*, "wise men," i.e. philosophers), but his first quote conflates several verses into one, drawing on Job 5:12–14, where God "frustrates the plans of the crafty" (*panourgôn*), "catches the wise in their thought" (*phronêsis*), and "thwarts the advice of complex men," who are lost in darkness and grope around in the day as if it were night. Instead, Paul says God "catches the wise in their craftiness" (*panourgia*), thus equating all three types of men, and identifying the *sophos* with men who are lost in the dark (a metaphor we'll see Paul using elsewhere).

1680. 1 Corinthians 8:1–2.

1681. Ephesians 4:13–15. On Clement's use of this metaphor see section 5.1.

1682. Ephesians 4:17–18. The author pretending to be Paul here says "walk" using *peripatein*, which may imply an allusion to the Aristotelians, who were called the Peripatetics because they began by teaching in the Peripatos, the "walking area" of temples (just as the Stoics began teaching in the Stoa, the "Porches").

1683. Wisdom of Solomon 9:13–18.

1684. Romans 1:19–25 (cf. Moo 1996: 95–108). Since it was the natural philosophers who catalogued and studied the evidence Paul refers to here (the empirical evidence of God's creation), and yet supported paganism or pantheism or atheism instead of the 'truth', they are clearly among Paul's targets in this passage.

1685. Ephesians 1:18.

1686. 2 Timothy 2:14, 2:16 and 2:23, and 1 Timothy 1:6–7 and 6:3–4. These passages are discussed in Towner 2006: 104–21, 392–405 (most relevantly), and 514–51.

1687. Drury 2001: 1229.

1688. James 1:5–8 (cf. Adamson 1976: 55–61 and 1989: 267–75). The context is the pursuit of wisdom (*sophia*) through prayer, and though moral wisdom is here (as always) the Christian's principle concern, the argument nevertheless conveys a general belief that *all* doubters are unstable (since the form of the argument states this as a general principle and then applies it to the particular case). Note also how this approach to acquiring moral wisdom contrasts epistemologically with that of the philosophers, who uniformly argued this could only be gained by applying human reason to a valid knowledge of nature (see chapter 4.1 and 4.2).

1689. Luke 1:18–20.

1690. 2 Corinthians 10:4–5 (cf. Barnett 1997: 464–66). The war metaphor that Paul employs here echoes the idea of making philosophy the 'handmaiden' (i.e. slave) of faith. The connection is even more explicit in Origen, who references scripture on subjugating captive women taken in war as a metaphor for the proper Christian approach to philosophy (as discussed in Carrier 2016: 152).

1691. For example: James 3:13. This attitude has already been seen in previous sections among leading patristic authors (in sections 5.1 through 5.4).

1692. Carrier 2014a: 124–37. See references to Stark, Malina, etc., in the relevant note in section 5.6.I, where the concept of altered states of consciousness is also discussed (from both the modern and ancient perspectives), as well as the value of merely *claiming* to have had such experiences.

1693. James 5:13–18 (cf. Adamson 1976: 196–202). Later Christian responses to scientific medicine are discussed in section 5.7.

1694. For background on Justin and his apologetic

Section 5.7 Evidence from Christian Writers

1694. For background on Justin and his apologetic see *OCD* 782 (s.v. "Justin Martyr") and *ODCC* 915 (s.v. "Justin Martyr, St.").

1695. Justin Martyr, *Apology* 1.23.

1696. Justin Martyr, *Apology* 1.31.

1697. I discuss Justin's disdain for science education in more detail in Carrier 2016: 148–51.

1698. Cicero, *Prior Academics* (= *Lucullus*) 2.36.117.

1699. Justin Martyr, *Dialogue of Justin and Trypho the Jew* 2 (for the story of his conversion: 3–8; on how the venerability of scripture convinced him: 7–8).

1700. Justin Martyr, *Dialogue of Justin and Trypho the Jew* 30 (exorcism) and 39 (quotation and gifts of the spirit).

1701. Athenagoras, *A Plea for the Christians* 7 (for the observation that scripture was his only trusted source of 'evidence': 9–10). For background see *OCD* 195 (s.v. "Athenagoras") and *ODCC* 121 (s.v. id.).

1702. Aristides, *Apology* (esp. 2 and 16 in the Syriac edition, which represents the earliest known form of the text; the Greek version was heavily redacted in later centuries and thus is not authentic). For background see *ODCC* 101 (s.v. "Aristides").

1703. For background on Tatian see *OCD* 1433–34 (s.v. "Tatian") and *ODCC* 1579 (s.v. id.).

1704. Tatian, *Address to the Greeks* 29 (on scripture as the superior source of knowledge: 31–32; on his studying all the philosophical schools and finding them wanting: 35).

1705. Tatian, *Address to the Greeks* 2 (sections 1–3 and 25–26 also argue at length that philosophers have never produced anything great or noble but have all been immoral and vainglorious and have only contradicted each other, while ignoring God).

1706. Tatian, *Address to the Greeks* 26 (compare with Tertullian, *To the Nations* 2.4, discussed in section 5.2 above).

1707. For his entire assault on medicine see Tatian, *Address to the Greeks* 18. For a complete analysis see Amundsen 1995 and 1996: 158–74.

1708. For this Galenic ideal see chapters 2.7 and 3.9.II. On the various Christian responses to scientific medicine, in contrast to the reception of faith healing (or the mere embrace of suffering as inevitable or morally superior to finding a cure) see: Nutton 1984a, 1985: 45–53, and 2013: 293–98 (for pagan and Jewish context: 280–93); Ferngren & Amundsen 1996; Avalos 1999 (esp.: 57–58); and Amundsen 1982, 1995, and 1996 (though Amundsen fails to distinguish an acceptance of 'traditional' or 'textbook' medical treatment from the actual scientific values required to understand, discover, and improve scientific medical care, of which there is no evidence in the early Christian period). On similarly mixed Jewish attitudes as precursors to later Christian views see Amundsen 1982: 342–43 and Newmyer 1996. But the Jewish adage that "the best of physicians are destined for hell" (discussed in Rosner 1994) was not directed at medical science *as such* but the scruples of doctors and healers (of whatever training).

1709. Hippolytus, *Refutation of All Heresies* 1 (cf. 1.26.3). For background see *OCD* 687–88 (s.v. "Hippolytus (2)") and *ODCC* 773–74 (s.v. "Hippolytus, St.").

1710. Hippolytus, *Refutation of All Heresies* 10.8 and 10.34.2.

1711. Eusebius, *History of the Church* 5.28 (Carrier 2016: 150). See discussion in Walzer 1949: 75–86 and for background see *ODCC* 1242 (s.v. "Paul of Samosata").

Section 5.8 Assessment of Christian Hostility

1712. All of this from: Origen, *Against Celsus* 1.9–10. Galen made the same observation as Celsus regarding Christian education and epistemology in *On the Different Pulses* 2.4 and 3.3 (= Kühn 8.579 and 8.657) and in several lost works (see fragments and discussion in Walzer 1949: 10–74, updated in Gero 1990). A similar observation may be reflected in a comment by Marcus Aurelius, *Meditations* 11.3 (compare Walzer 1949: 15–16, 57–74).

1713. Origen, *Against Celsus* 1.9 and 1.13.

1714. Origen's educational values: Discussed here in chapter 4.9 and in Carrier 2016: 149–55.

1715. Lactantius's educational values: As quoted and discussed in Carrier 2016: 160–63.

1716. Lactantius, *Divine Institutes* 3.26 (the Christian gospel is also superior to philosophy because both the certainty of faith *and* threats of heaven and hell are necessary to belief: 3.27).

1717. Lactantius, *Divine Institutes* 3.27–28.

1718. Clement of Alexandria, *Stromata* 2.4, 5.13, 7.16 (cf. 2.2, 5.1, 6.9.78–79, 8.3; and Prophetic Eclogues 4.2); and Exhortation to the Greeks (= Protrepticus) 8.

1719. Clement of Alexandria, *Stromata* 6.10 (cf. 1.9). See Carrier 2016: 156–57.

1720. Clement of Alexandria, *Stromata* 6.11.92–95.

1721. Underlying psychology: Supporting evidence can be found in sections 5.1 through 5.4 and chapter 4.9 here and chapters nine and ten of Carrier 2016.

Section 5.9 Exceptions That Prove the Rule

1722. This is more or less confirmed in P. Harrison 1998 for the entire middle ages.

1723. As architect of the Pantheon library: Julius Africanus, *Kestoi* frg. 5.1. His preference for the fabulous is shown in R.M. Grant 1952: 109–12. For background see *OCD* 755; *ODCC* 915; *EANS* 450; Meissner 1999: 258–61. His only discernible works in science are brief and unoriginal (e.g. a summary weights and measures: *EANS* 39).

1724. Carrier 2016: 150–54. See: Jerome, *Lives of Illustrious Men* 63, 65, 69; and Eusebius, *History of the Church* 6.3.1–2, 6.15, 6.19.13, 6.29–31. Besides exchanging scholarly letters with Origen, Africanus was a student of Heraclas, who was in turn a student of Origen, who converted Heraclas from his previous devotion to Greek philosophy (in fact, Eusebius claims Africanus went to Alexandria specifically to study under the 'renowned' Heraclas).

1725. Eusebius, *History of the Church* 6.19.12–14.

1726. Origen, *On the First Principles* 2.11.4–7. This material should perhaps be received with caution. We only have this work in a Latin translation which "revised" the original "in directions his fourth-century editor Rufinus considered to be more orthodox" (Bynum 1995: 63–64), enough to launch a bitter enmity between Rufinus and Jerome, e.g. in Jerome's Apology for Himself against the Books of Rufinus he says Origen's teachings "had been changed by the translator so as to give them a more orthodox meaning" (1.6) and that Rufinus had "taken away words that existed" and "put in those that did not exist" (1.7; cf. also 2.11). Jerome's outrage at this moved him to produce his own faithful translation into Latin of Origen's *On the First Principles*, but this (being heretical) was not preserved. Though in other cases we can sometimes reconstruct or suspect what Rufinus changed, there is no way of knowing if or in what way Rufinus "revised" anything in the section of our concern, but since it is consonant with Origen's thinking elsewhere, it has probably not been much distorted.

1727. Origen, *On the First Principles* 2.7.4 (though see previous note). On how this inverts the Stoic version of the same expectation in Cicero, see chapter 4.2.

1728. Ellspermann 1949: 38–39.

1729. Arnobius, *Against the Nations* 2.69.1 ("life is built up and refined" by the arts, though when he gives examples all he offers is divination and astrology); 1.48.6 ("it *may* be laudable to know," *sit laudabile scire*); 1.49 (faith healing superior to medicine), argued further in 1.64; 1.48.5 (medicine is a suspect art); 3.23.5 (doctors often fail); 2.5.4 (converts abandon former beliefs). Notably, Arnobius was an accomplished pagan educator converted very late in life, who allegedly wrote this treatise to prove to his bishop that he was a sincere convert (cf. Ellspermann 1949: 54–55). See *OCD* 168 (s.v. "Arnobius") and *ODCC* 109 (s.v. id.).

1730. Jerome, *Lives of Illustrious Men* 73, who says the "greatness of his genius" is proven "by the volume which he wrote *On the Passover* and his ten books *On the Principles of Arithmetic*." For problems crediting accomplishments to Anatolius see R.M. Grant 1952: 116. For more on Anatolius generally: *DSB* 1.148–49, *ODCC* 58–59, *EANS* 73.

1731. Eusebius, *History of the Church* 7.32.6–12. See discussions in chapter 4.7 here and in Carrier 2016: 128–30. Eusebius does not say (as some translations have it) that Anatolius was asked to *found* this school. Since Eusebius says "the school of Aristotle's successors in Alexandria" he probably means a school that was already there (further evidence of which is included in the relevant notes in Carrier 2016: 128–31). The word *sustêsasthai* can mean "to be appointed to" or "to be recommended to" or "to be joined to" or "to establish." Eusebius could have chosen a wording that more clearly indicates founding a school, but instead chose a word that most commonly means "joining membership with." The word for "school" (*diatribê*) also suggests an occupation more than an institution. So Eusebius probably means Anatolius was appointed a member or even the municipal chair in Aristotelian philosophy at Alexandria (so Marrou 1964: 286, 573 n. 13 = Marrou 1956: 190, 410).

1732. Eusebius, *Preparation for the Gospel* 14.2.7, 14.3.6, 14.13.9 (and see section 5.4).

1733. Hippolytus, *Refutation of All Heresies* 4.12 (Hippolytus even says the 'only' use for Ptolemy's calculations of celestial distances would have been in explaining to the builders of the Tower of Babel that heaven was too far to reach). For more on Hippolytus and his attitude to science see near the end of section 5.7.

1734. Hippolytus, *Refutation of All Heresies* 4.8–11.

1735. Hippolytus, *Refutation of All Heresies* 4.1–27 and 5.1.

1736. Hippolytus, *Refutation of All Heresies* 1.pr.8–11 (and cf. 1.26.3–4 and 10.2–4).

1737. This growth of Christian hostility and its eventual defeat (by tracking attitudes toward 'curiosity') is surveyed in P. Harrison 2001 (supported by Neil 2004: 99–138).

Section 5.10 Medieval Christianity

1738. See relevant discussion in chapter 3.8.IV.

1739. Lindberg 1992: 149. Lindberg 2007 updated 1992, but made no significant changes to the text pertaining to this (2007: 148) or the discussion to follow.

1740. In fact he cites only himself: Lindberg 1986 (repeating material from Lindberg 1983) and Lindberg 1987.

1741. Real science is a curiosity-driven empirical quest for progress in the knowledge of nature. Which is the result in practice of the "scientific spirit" as discussed in chapter 3.8.IV.

1742. Augustine's latent hostility to science: See the analysis in the early chapters of P. Harrison 1998 (especially regarding Augustine, *City of God* 22.24), and in Beck 2006: 170–75.

1743. Lindberg 1992: 151–90 and 317–25 (2007: 150–203, 321–28) presents his survey of medieval science before the 12th century; and of Islamic developments: 175–80 (2007: 163–92; on the tenuous and ultimately doomed status of science under Islam, cf. Cohen 1994: 384–417); and of the early Renaissance (12th to 14th century): 190–244, 325–54, 355–68 (2007: 193–203, 329–56, 357–68). This agrees with the findings of other scholars, e.g. Crombie 1959 and 1994 and Clagett 1955: 135–36, 146–82. As to what should count as a "significant" scientific achievement, see chapter 1.1.

1744. Hence Lindberg 2002a (also Lindberg 1986 and 1983) fails to produce a single counter-example to the argument of this chapter from the first three centuries, and only proposes two from the 4th century, Basil and Augustine, yet neither of whom present a particularly good counter-example (consider Augustine, *Handbook on*

Faith, Hope, and Charity 9 and *Confessions* 10.35; Basil, *Hexameron* 1.8–11; etc.; and see Lindberg 1983: 521–30 and R.M. Grant 1952: 115, 118–19), nor was either entirely representative of their peers. In Lindberg 2007: 363 he claims John Philopon conducted experiments, but there is actually no evidence that's true (see note in Chapter 1.1). He was also condemned as a heretic; and was wholly unrepresentative of his era.

1745. Lindberg 1992: 149–51 (2007: 148–50).

1746. Lindberg 1992: 157; cf. 151–59 (2007: 156–57; cf. 150–62).

1747. Lindberg 2002b: 62–63. Not even Lindberg 2007 (the new edition of Lindberg 1992) added any new evidence or arguments on this point. Nor did Lindberg 2009, which rests only on two false assertions bordering on flat out lies: that "Alexandrian science and mathematics prospered for decades" after the murder of Hypatia in the early 5th century (p. 9) and "some of the most celebrated achievements of the Western scientific tradition were made by religious scholars" (p. 17)—when in fact not a single significant advance would be made in mathematics or science for almost a thousand years after her death (much less any of "the most celebrated"). It's as if Lindberg wants to pretend those thousand years didn't even exist and aren't evidence of anything. Compare Efron 2009 in the very same volume; and Carrier 2010 and 2014b.

1748. Bad science in Christian authors: See examples in Clagett 1955: 136–82.

1749. No scientific function for these baths, fountains, or latrines was claimed by their excavators, nor plausible to imagine: Majcherek 1999, 2010, 2013.

1750. Netz & Noel 2007.

1751. Clagett 1955: 156.

1752. Berggren & Jones 2000: 43.

1753. "What's extant, is still the tiniest fraction of what was produced": See, for example, chapter 3.8.IV. Consulting the manuscript history for nearly any ancient science book usually reveals the same result.

1754. Christianity had to rediscover pagan values: Argued in Lloyd 1981, Russo 2003: 332–36 (with support in 336–97), and (for medicine) Nutton 2013: 323–24.

Chapter Six

Section 6. Conclusion

Section 6.1 Results

Section 6.2 Applications

1755. Ben-David 1991: 306.

1756. Political freedom was a different matter. See sources on intellectual freedom in chapter 1.1.

1757. Edelstein 1952: 600.

1758. Crombie 1963: 7.

1759. Third century chaos began the decline: As I argue in chapter 3.1 and also discuss in chapter 1.1. Commonly called "The Crisis of the Third Century," this conjoined a fifty-years-long civil war (from 235 to 284 A.D.) with the Plague of Cyprian (likely smallpox, wiping out a quarter to a half of the population between 250 and 270 A.D.), concluding in a Great Depression (with the collapse of the fiduciary economy by 270 A.D.).

1760. As demonstrated in Carrier 2016.

1761. "Does not indicate that scientists held a low social status, then any more than now." As argued in chapter 1.1 and the introduction to Carrier 2016.

1762. Lloyd 1981: 261–62.

1763. Ancient scientific societies: Carrier 2016: 124–30 (cf. 109 n. 286) Ancient universities: Carrier 2016: 130–33.

1764. Specialized labels included: *astronomos* or *astrologus* ("astronomer"), *architectus* or *mechanicus* ("engineer"), *iatros* or *medicus* ("doctor"), *mathematicus* or *geometres* ("mathematician"), etc., some with even more specializations distinguished within these.

Section 6.3 Speculations

1765. In chapter 1.1 here and in Carrier 2016: 90–91 (for estimates of the number of scientists: 29–31).

1766. Effect of numbers: This is partly the thesis of Sawyer 2007 (though his emphasis is on the role of collaboration) and Collins 1998 (who emphasizes interaction networks).

1767. I proposed an example of this 'impact' thesis in chapters 3.10 and 4.7, though as shown there, a scientific revolution can also be the result of accident rather than a consequence of greater numbers.

1768. Ancient universities: Carrier 2016: 130–33.

Appendix A on Ancient Exploration 553

I have not discussed explorers as scientists in this book. But those interested in that subject may benefit from this reference summary.

Eratosthenes is one of the first scientists to accept the reports of the explorer Pytheas of Massalia, who was possibly the first Greek to engage in large scale exploration for the sake of mere knowledge, going as far as Britain and beyond in the late 4th century B.C. (*DSB* 11.225-26; *EANS* 711-12; *OCD* 1247). On Pytheas and other ancient explorers see Cary & Warmington 1963, Hawkes 1977, Henze 1998, Russo 2003: 112-14, Roller 2006, and Kowalski 2012. A brief survey of Roman-era exploration is included in Berggren & Jones 2000: 23-30, 145-62, with discussion of the values that motivated it in Beagon 1992: 180-91. See also *OCD* 32-33, 611-12, 752, 1108-09, 1353 (s.v. "Africa (Libya), exploration," "geography," "itineraries," "*periploi*," "Seres") and *EANS* 447 (s.v. "Itineraries") and 999-1002 (s.v. "geography"), with Dilke 1985: 130-44 and the brief survey in Strabo, *Geography* 1.2.1. On geographical writers in general see Dilke 1985: 55-71.

In addition, for uncertain examples, see *OCD* 950 (Metrodorus of Skepsis; cf. *EANS* 555), 1092 (Patrocles of Macedon; cf. *EANS* 628), and 1335 (Scylax of Carvanda; cf. *EANS* 745-46, both actual and pseudo); and the 4th century traveler Anaxicrates (*EANS* 74). Likewise see *OCD* 229 (s.v. "bematists") for Eratosthenes' use of the official surveyors of Alexander the Great. See also the personal explorations of Alexander's compatriots (Androsthenes: *OCD* 86, *EANS* 82; Nearchus: *OCD* 1004, *EANS* 568-69; Onesicritus: *OCD* 1039, *EANS* 591-92) and those of subsequent kings (cf. Geminus, *Introduction to Astronomy* 16.24 and Strabo, *Geography* 17.1.5). Later explorers who contributed significantly to geography include Eratosthenes' student Mnaseas of Patara (*OCD* 965, *EANS* 559) and the historian Polybius (*OCD* 1174-75, *EANS* 680-81; though his geographical works are now lost, cf. Geminus, *Introduction to Astronomy* 16.32-33), then at the end of the 2nd century B.C., Posidonius (on whom see chapter 3.3 here), Eudoxus of Cyzicus (*OCD* 546, third entry; *EANS* 314), Artemidorus of Ephesus (*OCD* 175-76, second entry; *EANS* 165), and others (see Polybius, *Histories* 3.58-59), as well as expeditions financed by King Juba a century later (*OCD* 777, s.v. "Juba (2) II"; cf. *EANS* 441-42), and countless reports published by Roman magistrates and commanders (e.g. *OCD* 755, s.v. "Iulius Agricola, Gnaeus").

Detailed travel accounts were also written, e.g., in the 2nd century B.C. (Agatharchides of Cnidus: *OCD* 35, *EANS* 40-41; Scymnus: *OCD* 1335, *EANS* 746), in the 1st century B.C. (*OCD* 933, s.v. "Menippus (2)"; *EANS* 548-49), and in the 2nd century A.D. (*OCD* 169, s.v. "Arrian (Lucius Flavius Arrianus)"; cf. *EANS* 330). Many more explorations and accounts existed, most serving military or mercantile purposes, though some for tourists (e.g. *OCD* 1097, s.v. "Pausanias (3)"; cf. *EANS* 630-31). But there were also amateur armchair geographers who have no claim to being scientific, e.g. Pomponius Mela in the 1st century A.D. (*DSB* 11.74-76, *EANS* 685-86, *OCD* 1182), probably comparable to the lost *Geography* by Cornelius Nepos a century earlier (*OCD* 380, *EANS* 219-20, *NDSB* 2.81-84). There were other nonscientific 'descriptive geographies' from the 3rd century B.C. on (e.g. Polemon of Ilium: *OCD* 1169, third entry; *EANS* 678) including hack literary efforts (e.g. Gaius Iulius Solinus: *OCD* 764, *EANS* 455-56; Iulius Titianus: *OCD* 764, *EANS* 456).

Appendix B on Science before Aristotle 555

For good general summaries of Greek science and natural philosophy up to Aristotle see Lloyd 1970, J. Barnes 1982, Kirk et al. 1983, Allen 1991, Warren 2007, Vamvacas 2009, and Graham 2006 and 2013; also the valuable comments in Russo 2003: 22-24, 33-38, 48-49 and background in *OCD* 1207-08 (s.v. "Presocratic philosophy"). For ancient perspective see the relevant sections of Diogenes Laertius, *Lives and Opinions of Eminent Philosophers*. After Aristotle, natural philosophy tracks the major philosophical sects (directly or eclectically).

Although all of the following listed philosophers wrote books, some of them a great many books, almost all their writings are lost. We have to reconstruct our knowledge of them and their writings and accomplishments through other authors and evidence. The following names are chosen here for their importance to the history of science and the availability of their discussion in standard references (many more could be named; a more complete list is available in *EANS*). All dates are B.C.

Pre-Aristotelian natural philosophers include the **Ionians** Thales (7th to 6th century: *DSB* 13.295-98, 4.463; *EANS* 779; *OCD* 1448), Anaximander (early 6th century: *DSB* 1.150-51; *EANS* 75-76; *OCD* 83), Anaximenes (of Miletus, early 6th century: *DSB* 1.151-52; *EANS* 76; *OCD* 83), Heraclitus of Ephesus (late 6th century: *DSB* 6.289-91; *EANS* 372-73; *OCD* 665), Xenophanes (late 6th and early 5th century: *DSB* 14.536-37; *EANS* 839; *OCD* 1580), Anaxagoras (early 5th century: *DSB* 1.149-50; *EANS* 73-74; *OCD* 82-83), Hecataeus (of Miletus, early 5th century: *DSB* 6.212-13; *EANS* 361; *OCD* 649), and Scythinus (late 5th and early 4th century: *OCD* 1336; *EANS* 746); the **Sicilians** Empedocles (early 5th century: *DSB* 4.367-69; *NDSB* 2.395-98; *EANS* 283-84; *OCD* 503-04), and Ecphantus (4th century: *EANS* 280-82) and Hicetas (5th century: *DSB* 6.381-82; *EANS* 397; *OCD* 682) of Syracuse; the **Italians** Pythagoras (late 6th century: *DSB* 11.219-25; *EANS* 714-15; *OCD* 1245-46), Parmenides of Elea (early 5th century: *DSB* 10.324-25; *EANS* 626; *OCD* 1082), Zeno of Elea (5th century: *DSB* 14.607-12; *EANS*

844-45; *OCD* 1587), Menestor (5th century: *OCD* 932; *EANS* 547-48), Philolaus of Crotona (late 5th century: *DSB* 10.589-91; *EANS* 651-52; *OCD* 1133), and Philistion of Locri (late 5th and early 4th century: *OCD* 1130; *EANS* 649-50); the **Athenians** Archelaus (early 5th century: *OCD* 138-39; *EANS* 158), Hippon (5th century: *OCD* 689; *EANS* 421), Antiphon (late 5th century: *DSB* 1.170-72; *EANS* 99; *OCD* 108, first or second entry), Meton (late 5th century: *DSB* 9.337-40; *EANS* 551-52; *OCD* 942-43), Antisthenes (late 5th and early 4th century: *OCD* 109; *EANS* 99-100), and of course Aristotle's own teacher, Plato (late 5th and early 4th century: *DSB* 11.22-31; *EANS* 667-70; *OCD* 1155-58) and Plato's other pupils, e.g. Xenocrates of Chalcedon (*DSB* 14.534-36; *EANS* 838; *OCD* 1580). On the pupils also of Socrates (*OCD* 1378-79) see Carrier 2014a, p. 290 n. 19.

There were also the early **atomists** Democritus (who wrote on many subjects, from mathematics to biology: *DSB* 4.30-35; *EANS* 235-36; *OCD* 437-38) and his teacher Leucippus (*DSB* 8.269; *EANS* 506; *OCD* 824, third entry), together spanning the 5th century (*OCD* 200-01, s.v. "atomism"); their contemporary and more eclectic Diogenes of Apollonia (*OCD* 456; *EANS* 252); and Democritus' pupils Metrodorus of Chios (*OCD* 950; *EANS* 554) and Nausiphanes of Teos (*OCD* 1002; *EANS* 568), both early 4th century. Of special importance to the pre-Aristotelian development of scientific medicine is Hippocrates of Cos (late 5th century to early 4th century: *DSB* 6.418-31; *EANS* 404-05, with 406-20; *OCD* 687-88), more of whose works have been preserved than for anyone else listed here, although many are believed written or edited by his pupils and successors (for an extensive discussion of Hippocrates and early Hippocratism see Nutton 2013: 37-103, with Lloyd 1978). Lesser known today (since nothing he wrote survives), but in antiquity a famous contributor to medical science, was Democedes of Croton in the 6th century (*OCD* 434; *EANS* 234).

Pre-Aristotelian **mathematicians** (some of whom studied harmonics, others astronomy) include Pythagoras (above) and Hippasus (6th century: *OCD* 686; *EANS* 399-400), Democritus (above), Bryson of Heraclea (5th century: *DSB* 2.549-50; *EANS* 199-200; *OCD* 254), Euctemon of Athens (5th century: *DSB* 4.459-60; *EANS* 317; *OCD* 545), and Oenopides of Chios (5th century: *DSB* 10.179-82; *EANS* 587; *OCD* 1034); from the late 5th century: Hippias of Elis (*DSB* 6.405-10; *EANS* 400; *OCD* 687, first or third entry), Hippocrates of Chios (*DSB* 6.410-18; *EANS* 401-03; *OCD* 689, third entry), Theodorus of Cyrene (*DSB* 13.314-19, 15.503; *EANS* 785-86; *OCD* 1458, second entry), Eratocles (*OCD* 533; *EANS* 297); and (contemporary with Aristotle): Theatetus of Athens (late 5th to early 4th century: *DSB* 13.301-07; *EANS* 780-81; *OCD* 1449), Theudius of Magnesia (early 4th century: *DSB* 13.334; *EANS* 805), Archytas of Tarentum (early 4th century: *DSB* 1.231-34; *EANS* 161-62; *OCD* 145), Aristoxenus of Tarentum (early 4th century: *DSB* 1.281-83; *EANS* 153-55; *OCD* 163-64), Thymaridas of Paros (early 4th century: *DSB* 13.399-400; *EANS* 808-09), Eudoxus of Cnidus (early 4th century: *DSB* 4.465-67; *EANS* 310-13; *OCD* 545-46, (1)), Leo of Athens (early 4th century: *DSB* 8.189-90; *EANS* 502), Leodamas of Thasos (early 4th century: *DSB* 8.192; *EANS* 502), Menaechmus (4th century: *DSB* 9.268-77; *EANS* 542-43; *OCD* 929, second entry), Heraclides Ponticus (4th century: *DSB* 15.202-05; *EANS* 368-69; *OCD* 664), Aristaeus (4th century: *DSB* 1.245-46; *EANS* 130-31), Speusippus (4th century: *DSB* 12.575-76; *EANS* 756-57; *OCD* 1393), Dinostratus (4th century: *DSB* 4.103-05; *EANS* 229-30), Philippus of Opus (late 4th century: *OCD* 1130; *EANS* 647), and Callippus (late 4th century: *DSB* 3.21-22; *EANS* 464-65; *OCD* 267-68).

Scientific dissection may have begun as early as the late 6th century under the Sicilian natural philosopher Alcmaeon of Croton, but this is disputed (*DSB* 1.103-04; *EANS* 61; *OCD* 54). We only hear of it a thousand years later, and Aristotle does not appear to have known of it, even though he extensively studied the work of his predecessors, yet Alcmaeon's alleged achievements would have greatly altered Aristotle's conclusions on fundamental elements of physiology. There were also scientists writing treatises on mechanics and engineering during or before Aristotle's time, e.g. *Diades* (4th century; EANS 243-44).

Appendix C on the Books of Sextus Empiricus 559

Two books survive from Sextus Empiricus: *Outlines of Pyrrhonism* and *Against the Professors*. However, it is now believed the treatise entitled *Pros Mathêmatikous* ("Against the Professors") is actually a modern merging of two separate works or more (e.g. J. Barnes 1988: 53). Of this the first six books comprise the original contents of *Against the Professors*, but the remaining books belong to something else, some of which may be missing. I use the traditional numeration for the latter books because it is simpler and less confusing. But to convert them use the following table:

Against the Professors	= *Against the Dogmatists*	= *Against the ...*
7	1	... *Logicians* 1
8	2	... *Logicians* 2
9	3	... *Natural Philosophers* 1
10	4	... *Natural Philosophers* 2
11	5	... *Moral Philosophers*

END FILE