

Konoval, B. What does science have to do with music? Andrew Barker, "Scientific method in Ptolemy's harmonics". Charles Kahn, "Pythagoras and the Pythagoreans: a brief history". Jamie Kassler, "Music, science, philosophy: models in the universe of thought". *Annals of science*. 2005, 62, 1, p 107-121.

## Essay Review

### What Does Science Have to Do with Music?

ANDREW BARKER, *Scientific Method in Ptolemy's Harmonics*. Cambridge: Cambridge University Press, 2000. viii+281 pp. \$70. ISBN 0-521-55372-5.

CHARLES H. KAHN, *Pythagoras and the Pythagoreans: A Brief History*. Indianapolis and Cambridge: Hackett Publishing Company, Inc., 2001. xi+195 pp. Cloth, \$34.95; paper, \$14.95. ISBN 0-87220-576-2; ISBN 0-87220-575-4.

JAMIE C. KASSLER, *Music, Science, Philosophy: Models in the Universe of Thought*. Variorum Collected Studies Series. Aldershot, Hampshire, and Burlington, Vermont: Ashgate Publishing Company, 2001. xvi+301 pp. \$111.95; £59.50. ISBN 0-86078-862-8.

#### Reviewed by

BRANDON KONOVAL, *Arts One Programme and the School of Music, The University of British Columbia, Vancouver, B.C. Canada*

In 1737, a French composer and music theorist who was not prone to half measures announced a major discovery, the product of recent scientific research and his own enlightened application of it: 'All the principles which had been asserted to be the foundation of music, whether by the ancients or the moderns, were not themselves principles, but rather arose from the true principle of music—that is, from the harmony which results from the resonance of one sonorous body'. The author was Jean-Philippe Rameau (1683–1764) and his nominal audience, the members of the Académie Royale des Sciences, to whom Rameau's *Génération harmonique* was dedicated.<sup>1</sup> Rameau had been deeply impressed by Joseph Sauveur's research into the behaviour of sonorous bodies, as detailed in the *Système générale des intervalles des sons* (1701), and he now proposed to wield the overtone series of the *corps sonore* as though it were the Ockham's razor of music: a device with which he could neatly demonstrate the genuine anatomy of musical practice to reveal, in Fontenelle's phrase, a 'music provided by nature herself'. And yet, although boldly he wrote (and well), Rameau failed to procure membership in the Académie with his treatise.

Rameau may have been the victim of good press: many of his contemporaries referred to him as the 'Newton of harmony', an epithet that the Académie evidently found itself rather shy to embrace. Nonetheless, Rameau's confidence that science would take a deep interest in musical matters was no immoderate presumption, for music was a favourite preoccupation of the era's intellectual establishment, and Rameau himself was a widely acknowledged authority who enjoyed both the interest

<sup>1</sup> The quotation is taken from the preface of the treatise, as translated by Deborah Hayes in *Rameau's Theory of Harmonic Generation: An Annotated Translation and Commentary of 'Génération harmonique' by Jean-Philippe Rameau*, Ph. D. dissertation, Stanford University, 1968 (Ann Arbor: University Microfilms, 1970), p. 18.

955 418  
KONOVAL, B.  
2005

and, at times, the support of the philosophes and figures like Bernoulli and Euler.<sup>2</sup> How greatly things appear to have changed, then, when we read the acknowledgments of Jamie Kassler's *Music, Science, Philosophy: Models in the Universe of Thought*, a collection of articles spanning almost thirty years of scholarly research that has been principally devoted to interests held in common by music and the history and philosophy of science. Kassler expresses special gratitude for the support of the late Roy Porter, who chose to publish Kassler's first articles, 'even after the referee of one of those articles asked: "what does music have to do with science?"' (p. xv)

The question is as broad as it is pointed—odd proportions, to be sure, but no less deserving of a considered response for that. Kassler appreciated its sincerity, to judge from the wide range of thought-provoking articles that were to follow, many of which have been brought together in the present volume.<sup>3</sup> However, Kassler has certainly not stood alone in responding to this challenge: in the years since the referee's query, scholars have done much to address the question as one of legitimate historical and philosophical concern, with several producing research of extraordinarily acute observation and rich erudition. In English alone, this literature is already too extensive to be given its due in any brief account.<sup>4</sup> Yet, a few recent publications by established historians including Kassler inform us of how the shared concerns of music and the history of science are faring in the academy nearly three centuries after Rameau.

Of course, the question, 'what does music have to do with science?' suggests a pronounced dissonance between its key terms. That the relationship between music and science could be perceived to be under some tension is not difficult to appreciate, given the lingering echoes of Orpheus and his lyre: a pagan saint of the western musical tradition whose death-defying feat occasioned the earliest ventures into western opera, Orpheus is perhaps more symbolic of the desire to defy rather than define natural law. Nonetheless, there are other mythological figures who speak to the curious status of music as an art that both reveals and challenges the rational. In the first essay of the collection, Kassler recounts traditional associations of 'Apollinian' and 'Dionysian' music:

The intelligible, determinate and mensurable domain of Apollo's order...was opposed to the fantastic, vague and shapeless domain of Dionysus' disorder. These two domains were further distinguished by the music and musical instruments associated with each. On the one hand, Apollo's concordant music quelled the passions; and his instrument [the *kithara*] was the model of proportional tuning systems based on rational numbers. On the other hand, Dionysus' dissonant and 'barbarous' music raised the passions; and his instrument [the *aulos*] produced its sounds by air pressure and, hence, required tempered systems based on irrational numbers. (p. 2)

<sup>2</sup> Ibid., pp. 263–264. There have been numerous articles of interest concerning Rameau's association with the luminaries of the Enlightenment and their thought. The classic study is Thomas Street Christensen, *Rameau and Musical Thought in the Enlightenment* (Cambridge, 1993).

<sup>3</sup> The collection is not exhaustive. For example, Kassler's articles for *History of Science*, 'Music as a Model in Early Science', 20 (1982), 103–39; 'Man – A Musical Instrument: Models of the Brain and Mental Functioning before the Computer', 22 (1984), 59–92 are not included.

<sup>4</sup> Myles Jackson offers a concise, critical overview of some of the more noteworthy works concerned with music and the history of science of the past 20 years, specifically, works principally concerned with sixteenth and seventeenth century developments, in 'Music and Science During the Scientific Revolution', *Perspectives on Science*, 9 (2001), 106–15.

This rather tidy distinction between the Apollinian and the Dionysian, with its echoes of early Nietzsche, refers to many of the classic (and classical) concerns of music theory and instrument use—concepts of consonance and dissonance, for example, and their relationships to systems of tuning—to which I will return. (It also serves to introduce an intriguing account of Karl Popper's interest in musical matters and their relationship to scientific pursuits, which provided him with the opportunity to play upon familiar themes.) But what is of special interest is Kassler's reminder to readers that what is often taken to be the 'scientific' aspect of music—what could be called the 'Apollinian' concern with numerical ratios of pitch relationships, for example, and the related psychoacoustic phenomena addressed by systems of tuning—has associations no less mythical than those of 'Dionysian' passion and irrationality. This is a salutary reminder indeed when one tries to come to terms with the *fons et origo* of the relationship between music and western science, the Pythagorean tradition, and no less so with the figure of Pythagoras himself.

The Pythagorean tradition is certainly a rich and diverse one, concerning itself with issues that encompass both the mundane world of musical practice and the music of the spheres. Yet, it is a notoriously difficult tradition to get a grip on—if 'tradition' is an appropriate handle for such a protean beast—and this difficulty is due in no small measure to its mysterious figurehead. In a relatively recent work of scholarship that offered a major contribution to the study of music and the history of science, Bruce Stephenson—not one to shrink from the recondite—throws up his hands where many have thrown theirs up before: 'Pliny, that amiable first-century story-collector, had a story about the music of the heavens. He attributed it to Pythagoras, of course, and perhaps he was right—who knows?'<sup>5</sup> Who does, indeed? There are no writings directly traceable to the historical Pythagoras: what we know of his ideas, convictions, beliefs and purported accomplishments comes from his followers, and these were a diverse bunch who spread out over many lands and, ultimately, through many centuries. However, even if one has no particular interest in the historical Pythagoras, we cannot overlook the place that both he and the 'Pythagorean' tradition have held in the history of science, and so we are all left with the conundrum faced by Stephenson: what, if anything, can be understood by reference to Pythagoras or, for that matter, to the term 'Pythagorean'?

Alas, this is once again a question of unwieldy but familiar proportions, both pointed and broad. We are not aided by the fact that, no sooner do we encounter the term 'Pythagorean' than we find ourselves plunged deep in a doxographic quagmire of associated referents such as 'Neopythagorean', 'Platonic' and 'Neoplatonic', terms that defy consistent demarcation.<sup>6</sup> Confronting such uncertain terrain, we can

<sup>5</sup> Bruce Stephenson, *The Music of the Heavens: Kepler's Harmonic Astronomy* (Princeton, NJ., 1994), p. 23.

<sup>6</sup> Thomas Kuhn promoted a fairly neat conceptual division for interested historians of science—'the mathematical strain in Neoplatonic thought is often attributed to Pythagoras and identified as Neopythagoreanism'—a suggestion that more recent scholarship has found some cause to support, at least with respect to the Neopythagoreanism of late antiquity. See Thomas S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, MA., 1957), p. 128. The origins of this perspective have been carefully examined by Dominic J. O'Meara in *Pythagoras Revived: Mathematics and Philosophy in Late Antiquity* (Oxford, 1989), who suggests that prominent 'Neoplatonists' regarded Plato's teachings as an attenuated Pythagorean philosophical tradition in need of rejuvenation, particularly with respect to its mathematical orientation. O'Meara's account can be compared with an earlier work covering similar terrain, R. T. Wallis's *Neoplatonism* (1972; Hackett reprint, 1995), where 'Pythagoreanism' remains in the shadows.

welcome the assured guidance of Charles H. Kahn, author of a major study of Anaximander,<sup>7</sup> whose *Pythagoras and the Pythagoreans: A Brief History* surpasses the modest promise of its title. The work is a concise but rewardingly considered account that aims to untangle the fortunes of Pythagoreanism in its principal guises from as close to the point of origin as we can hope to reach (with due caution) through to the advent of Kepler, whom Kahn identifies as arguably ‘the last Pythagorean’.<sup>8</sup> (p.171) Kahn has judiciously chosen the figures and texts highlighted in this study, and his account is all the more impressive for the pleasure one discovers in following the twists and turns of the Pythagorean legacy as it is traced from Philolaus and Plato through the Hellenistic period, and from the Rome of Cicero and Varro through late antiquity and into the early modern era.

What makes this journey all the more engaging is the clarity with which Kahn explores the frequently abstruse texts that fueled so much commentary and speculation, enabling readers to intelligibly appreciate both the harmony and counterpoint of Pythagorean interests. The result is a balanced study that does not focus exclusively on the traditions of the *mathêmatikoi*, yet historians of science should not be impatient with the attention to moral or religious concerns of the Pythagoreans; for, as Plato’s *Timaeus* advises us while recounting a deeply Pythagorean creation myth:

the god invented sight and gave it to us so that we might observe the orbits of intelligence in the heavens and apply them to the revolutions of our own understanding. For there is a kinship between them, even though our revolutions are disturbed, whereas the universal orbits are undisturbed. So once we have come to know them and to share in the ability to make correct calculations according to nature, we should stabilize the straying revolutions within ourselves.... [*Timaeus*, 47C]<sup>9</sup>

The enjoinder to contemplate of the works of a creator god so that we might suitably harmonize our souls helped to sustain the vitality of the Pythagorean/Platonic legacy through the Medieval period and into the early modern era. As Kahn notes in his discussion of Nicholas of Cusa, ‘Nicholas’s world view emerges from an authentic Platonic-Pythagorean background’—a background that Kahn characterizes as that of ‘a Catholic cardinal working in the tradition of Christian Neoplatonism’—‘but at the same time it prefigures the new mathematical science of nature’. (p. 158–9) In a work that strives to be concise but never glib, one can readily appreciate a reluctance to take on the Pythagorean aspects of medieval Christian Neoplatonism. Yet, this is the one appreciable gap in Kahn’s brief history, which hops over an era of significant historical continuity that earlier discussion has left us

<sup>7</sup> *Anaximander and the Origins of Greek Cosmology* (Indianapolis, 1960; Hackett reprint, 1994).

<sup>8</sup> One is also tempted to consider the less demonstrative case of Newton. J. E. McGuire and P. M. Rattansi’s article, ‘Newton and the Pipes of Pan’, *Notes and Records of the Royal Society of London*, 21 (1966), 108–43 details a connection Newton wished to draw in his so-called ‘Classical Scholia’ between the law of inverse squares and the Pythagorean ‘music of the spheres’. Newton’s claims for a precursor depended upon a discovery by Vincenzo Galilei regarding the relationships of string tension which yield musical consonances, to be discussed later.

<sup>9</sup> I use the translation of Donald J. Zeyl (Indianapolis, 2000), pp. 35–36.

well prepared to comprehend.<sup>10</sup> If Nicholas' brand of Catholicism peculiarly suited him for the frontier of a 'new mathematical science of nature', then how might that Catholicism have been shaped by Pythagorean influences? Ironically, both the cover of the paperback and the frontispiece of the hardcover editions feature a sculpture from the series depicting the seven liberal arts on the Portail Royal at Chartres cathedral, with commentary noting that the sculpture—a figure bent over a monochord—is of Pythagoras himself. In a note, Kahn comments on 'the appropriateness of Pythagoras as the representative of music at Chartres', an appropriateness that we could appreciate all the more with some reference to the Pythagorean interests of figures of the so-called 'School of Chartres' like Thierry of Chartres and Gilbert of Poitiers.<sup>11</sup>

Coming to the early modern period, Kahn succinctly details Pythagorean themes in Copernicus and, especially, in Kepler's music of the spheres (albeit, without reference to Stephenson's classic 1994 study). Here, one might hope for more attention to specifically musical concerns, as Kahn's account elides important developments in music theory and musical practice of the sixteenth century that strongly affected the Pythagorean tradition and its influence on early modern science. When Kahn alludes to issues of musical tuning, he refers to what continued to be known (and used) throughout the medieval era and into the Renaissance as 'Pythagorean' tuning, which he juxtaposes with the use of temperament, an alternative approach to tuning that will be discussed below. What Kahn's account does not address is the noteworthy emergence of just intonation in the fifteenth century, a tuning system that responded empirically to developments in musical practice that would not continue to suit a Pythagorean framework of tuning. This development bears directly on a scientific text of major concern to Kahn, Johannes Kepler's *The Harmonics of the World* (Kahn's apt translation, rather than the conventional rendition, 'The Harmony of the World'—for details, see his comments in note 50, p. 162). Kepler tunes his cosmos with just intonation, and chose to do so on an apparently empirical basis.<sup>12</sup> Furthermore, the very 'Neopythagorean' numerology observed by Kahn in Augustine (pp. 153–4) was later re-enlisted in the service of just intonation, to encompass musical intervals defined by ratios of numbers lying outside the traditional Pythagorean *tetractus* of the numbers 1

<sup>10</sup> See Heinrich Fichtenau, *Heretics and Scholars in the High Middle Ages, 1000–1200*, translated from the German by Denise A. Kaiser (Pennsylvania, 1998), especially 'The Philosophical Myth: Platonists'. (pp. 172–96) Outside of the quadrivial works of Boethius, the principal textual conduit for Pythagorean ideas was Plato's account of the creation of the world soul in the first part of the *Timaeus*, which was available in twelfth-century libraries in the Latin translation and commentary of Chalcidius. As Fichtenau relates, many medieval Christian commentators drew from their understanding of Plato's creation story to address the textual challenges of the Genesis account. Earlier in his study, Kahn discusses the first century Platonist, Philo of Alexandria, who had undertaken a strikingly similar project (albeit without the Trinitarian concerns). For a detailed account, see Jaroslav Pelikan, *What Has Athens to do with Jerusalem? Timaeus and Genesis in Counterpoint* (Michigan, 1997).

<sup>11</sup> See Fichtenau (note 10), pp. 177–8 regarding the 'Pythagorean propositions' entertained by these figures. Kahn's comment is on p. 156, note 37.

<sup>12</sup> See Stephenson (note 5), in particular pp. 118–20; also relevant here is D. P. Walker's 'Kepler's Celestial Music' in *Studies in Musical Science in the Late Renaissance* (London, 1978), pp. 34–62, especially with respect to the empirical nature of Kepler's choice of just intonation (see pp. 47–48).

through 4.<sup>13</sup> Some modern-day commentators have viewed this numerological development as something akin to the monstrosity of epicycles, a desperate attempt to preserve an outmoded theoretical system. Indeed, they mark the end of the Pythagorean era with the arrival of a familiar surname, borne by a humble lutenist promoted as a scientific champion who defeats the Pythagorean numerological monster: Vincenzo Galilei (c.1530–1591), the father of that other Galilei.

In such an account there is, properly speaking, only one dogma of empiricism, which is that empiricism proper begins with Vincenzo Galilei. Vincenzo is here understood as someone who essentially restores the discipline of acoustics to the field of harmonics, which is otherwise portrayed as hopelessly enthralled to Pythagorean number mysticism.<sup>14</sup> Whatever we choose to make of such an account, it is instructive to consider the words of the champion himself, who looks back on the traditions of his illustrious predecessors and remarks:

We read...that the Pythagorean faction wished to pursue the reasoning with numbers in everything having to do with pitches and musical intervals, particularly the consonances that we call perfect. The Aristoxenians, on the contrary, say these writers, not valuing the reasoning of the Pythagoreans, submitted everything entirely to the judgment made by means of the sense of hearing. After them the Ptolemaics...sought to bring reasoning with numbers and the sense of hearing into agreement. But what exactly was the reasoning with numbers that Pythagoras wanted to pursue in his division of the strings? What was the sense of Aristoxenus? And what was the reason and sense that Ptolemy wanted to harmonize?<sup>15</sup>

These were genuinely pressing questions for Vincenzo, who was seriously concerned to harmonize the rational and the empirical in music theory and in musical practice. He would have gladly turned for assistance to Andrew Barker's latest contribution to our understanding of ancient music theory, *Scientific Method in Ptolemy's Harmonics*, a penetrating analysis of a most challenging and influential treatise that Vincenzo himself was deeply inspired by. (It is also worth noting here the close relationship between the *Harmonics* of Ptolemy and of Kepler, for Kepler himself set out to translate Ptolemy's work from the Greek and provide detailed commentary on it, some of which survives in the guise of the *Harmonice mundi*. As

<sup>13</sup> That is, the traditional ratios could be represented through use of the numbers 1 through 4, such as 1:2, 2:3, 1:4 and so on, which could be applied to the string or pipe lengths used to produce the pitches constituent of what are known as 'perfect' consonant intervals—the traditional Pythagorean intervals. In support of just intonation, we see a central Renaissance music theorist like Gioseffo Zarlino (1517–1590) employing numerological stratagems to justify the use of consonant intervals that require ratios involving the numbers 5, 6 and 8—these ratios correspond with musical intervals of the third and sixth that became immensely popular in Renaissance musical practice, but which were nearly inaccessible in a consonant form in Pythagorean tuning. Zarlino does this with reference to the idea of a 'perfect number', which happens to be 6—and which happily corresponds with Augustine's choice, too (6 days of creation, etc.). See Gioseffo Zarlino, *Le istituzioni harmoniche* 4 Parts (Venice, 1558), I, 14. Vincenzo Galilei, on the other hand, thinks that the perfect number should be 8, and for perfectly good empirical reasons.

<sup>14</sup> I am somewhat conflating the influential discussions by Claude Palisca, 'Scientific Empiricism in Musical Thought' in H. H. Rhys, ed., *Seventeenth Century Science and the Arts* (Princeton, 1961), 91–137 and Stillman Drake 'Renaissance Music and Experimental Science', *Journal of the History of Ideas*, 31 (1970), 483–500. The issues raised by these accounts are complex and cannot be adequately treated here.

<sup>15</sup> Vincenzo Galilei, 'Discourse Concerning the Various Opinions that the Three Most Famous Sects of Ancient Musicians had Concerning the Matter of Sounds and Tunings', in Claude V. Palisca, ed. and trans., *The Florentine Camerata: Documentary Studies and Translations* (New York, 1989), p. 165.

Stephenson observes, 'the belief that he shared his inspiration with so great a scientist strengthened Kepler's determination to do correctly what the Alexandrine astronomer had been unable to complete'.<sup>16</sup>) Barker is certainly well disposed to offer such analysis, having produced the immensely useful annotated translations of the broad corpus of ancient Greek writings on music, *Greek Musical Writings III* (Cambridge, 1984/1989), including a translation of Ptolemy's *Harmonics*.<sup>17</sup> His newer work is in the tradition of an extended commentary but with a particular focus on the methodology employed by Ptolemy, for he observes that, 'the more I studied it the clearer it became that it is a landmark of major significance in the contentious and quarrelsome history of reflections on scientific method'. (p. vii) Barker recognizes that the *Harmonics* is typically overlooked by historians of science in favor of the *Mathematike syntaxis* (or *Almagest*), not to mention the *On the Criterion*, but he argues that the *Harmonics*,

is quite unusually explicit and self-conscious about its own methodology and procedures. In this respect it has a great deal more to offer than the *Syntaxis*, whose overt reflections on the general features of the science are relatively brief and less directly methodological, and play a notably less prominent role in the development of the subsequent argument. The *Harmonics*, by contrast, announces and seeks to justify at the outset a sophisticated set of procedural principles which scientists in this field, so it argues, must follow if they are to produce defensible results. (p. 1)

What will be of particular interest to historians of science is that these principles involve experimental procedures, although Barker does not encourage a credulous reading of his subject in this regard, for 'there are often good reasons for treating warily the suggestion that this or that Greek scientist conducted genuine experiments to confirm or refute his hypotheses'. (p. 192).

Here, veterans still with us from the wars over Galileo and the use of experiment—did he or didn't he?—may find themselves in somewhat familiar terrain, although this is not a parallel suggested by Barker himself. In contrast to the other books under review, Barker's account is necessarily a concentrated one: 'I intend to keep the focus as sharp as possible, restricting myself to an examination of this single text, without drawing elaborate comparisons or attempting to generate large conclusions about Greek science in general'. (p. 3) Such focus is well considered, given the idiosyncrasies of Greek music theory. Although Barker might secretly hope that with Orphic powers of persuasion he could indeed rescue the subject from languishing 'in a cobwebby corner of our gallery of the Greek sciences', he is well aware that the *Harmonics* will remain a tough sell to those who don't know their *proslambanomenos* from their *nete hyperbolaion*. (p. 1) To this end, he has devoted exceptional care to his presentation of the intricacies of harmonics, on par

<sup>16</sup> Stephenson (note 5), pp. 4–6, as well as the full chapter devoted to the Kepler/Ptolemy association, 'The Reconstruction of Ptolemy's *Harmonics*', pp. 98–117.

<sup>17</sup> This is not the only full translation available in English. Jon Solomon has recently produced *Ptolemy Harmonics: Translation and Commentary* (Leiden, 2000), a work which Barker was not able to take into account for his extended commentary, although he notes that 'the problems posed by the text will be significantly eased by [this] detailed, scholarly study'. (p. 1, note 1) For his part, Solomon writes: 'the present text demands something much closer to the Latinate and literal style, and for this I owe no apologies. Ptolemy... would be surprised to find the English version of his treatise on harmonics fluid and pleasant going, and I did not see my function as a translator to rewrite the treatise and make it seem fluid and pleasant going'. (p. x)

with Stephenson's account of Kepler's harmonies, and the result can be an absorbing read for those who volunteer to become initiates.

For non-initiates, it might not be all that clear what 'harmonics' entails as a discipline, or what its involvement with scientific concerns might be. In brief, harmonics can be understood as the attempt to create feasible or acceptable attunements—that is, a means of selecting and determining pitch locations for musical use—and to articulate the principles that govern them. This has remained a long-standing challenge because of the often conflicting demands made by our preferences for tuning that an attunement must attempt to reconcile. Nowadays, we tend to think of attunement in terms of 'tuning musical instruments'—making a piano or a violin sound 'in tune', for example—rather than in terms of 'selecting pitch locations for musical use'. Likewise, the idea of an instrument being 'in tune' suggests something that we can judge solely 'by ear', relying fundamentally on a kind of sensory response. In fact, our instruments are tuned according to cultural traditions as much as they are tuned according to the supposed preferences of our ears, and our ears themselves are attuned to these traditions—traditions that inform and guide our preferences to varying extent, whether we are aware of this or not. 'Tuning' in the conventional sense—that is, the tuning of instruments, or simply singing or playing 'in tune'—is really a secondary activity: it aims to accurately reproduce a prior selection of pitch locations. The primary act of tuning is rather the very selection of those pitch locations, establishing their number and distribution relative to each other. Issues of interest to acoustics and psychoacoustics arise when we consider the basis on which we construct the number and relative distribution of these pitch locations.

The disharmony of the spheres might provide a helpful analogy at this point, for the creation of a calendar typically involves an attempt to reconcile conflicting preferences that is somewhat similar to the challenges faced in the creation of an attunement. Both are typically concerned with the problem of harmonizing different kinds of interval that 'nature' seems to recommend: in the case of the calendar, the lunar month and solar year, and in the case of attunement, different types of consonant musical intervals. The use of lunar phases to subdivide the solar year is notoriously problematic, as the year that would be constructed from twelve such phases falls well short of the solar period; likewise, to use one series of consonant intervals to subdivide the compass established by another interval or interval series produces gaps known as 'commas', of which there are various types (such as the 'Pythagorean' comma and the 'syntonic' comma), depending on the number and sequence of intervals used. As in calendar-making, one is not obliged to harmonize the differing interval periods of an attunement, so long as one is prepared to live with the consequences—essentially, the effects of the commas—just as a pure lunar calendar will suffice if its transit through the course of the seasons is found acceptable. In music, one fundamental concern is at stake: that our preference for certain intervals as constituent of a tuning will be disappointed if we encounter these intervals in a warped state—that is, in a state in which the size and perceived character of an interval has been altered by a comma—just as we might be disappointed if the month of October failed to reliably correspond with harvest season each year. Part of the discipline of harmonics, then, involves the careful distribution of the effects of a comma, just as a calendar that aims to reconcile lunar and solar intervals must find ways to suitably distribute the approximately

eleven-day ‘comma’ that obtains between the solar and lunar year. In this respect, then, harmonics can be understood as a form of calculation that takes certain empirical phenomena—our preferences for certain types of interval, for example—as both point of departure and goal, aiming to satisfy those preferences in the resulting attunement.

The mathematical features of harmonics have their roots in the Pythagorean tradition, where intervals that may be used as the basis for an attunement are defined by simple ratios involving the numbers 1 through 4. (see note 13) The intervals associated with these numbers—intervals corresponding to the ‘unison’, ‘octave’, ‘fifth’, ‘fourth’ and ‘twelfth’ in modern terms, if these intervals are tuned according to their exact ratios (known as ‘just’ ratios)—happen to sound very harmonious; indeed, in one class of ratio (referred to in modern terminology by the term ‘pitch class’), this blend is so harmonious that the constituent pitches sound as though they share one identity, a psychoacoustic phenomenon that is taken by most musical cultures to set the fundamental boundaries of attunement.<sup>18</sup>

The close correspondence between mathematical elegance—simple numbers in simple ratios—and musical consonance stimulated much contemplation of a potential relationship between the two, including the possibility that our perception of musical consonance was determined by our apprehension of a mathematical consonance on which the auditory form was ontologically dependent. Nonetheless, a kind of experimental tradition emerged in tandem with this that involved a device called a *kanon*, or what became known as the ‘monochord’—both terms referring to an instrument on which typically a single length of string under tension could be subjected to measurable divisions, and used to aurally judge the results of calculations with ratios.

In practical terms, the Pythagorean ratios of consonant intervals provided an obvious empirical basis for initial calculation in attunements, as these ratios were based on units of measurement appreciable as such to the ear: in fact, one of the attributes of ‘consonance’ itself appears to be the very possibility for a distinct interval identity, from which dissonant intervals may be derived.<sup>19</sup> Nonetheless, the empirical validity of these ratios—namely, that ratios of particular string lengths will indeed produce the interval claimed or predicted by theory—is something that we do not see taken for granted in Ptolemy’s *Harmonics*. One of Ptolemy’s recurrent

<sup>18</sup> The pitch class relationship can be defined in terms of ratios as  $1:2^n$ , where ‘n’ is an integer greater than or equal to zero, producing the series 1:1, 1:2, 1:4, 1:8 and so on. This relationship is typically referred to through the use of letter names: for example, the pitch class ‘C’, which will include both ‘middle C’ and all the other pitches perceived as ‘C’ above and below, all of which share equally in this pitch class identity. In general, most attunements strive to maintain the pitch class relationship, as it makes possible the integration of a wide range of instruments and voices. The usefulness of this is evident whenever people with distinctly different vocal ranges sing in unison, such as when children and adults sing a tune like ‘Happy Birthday’ together: if they cannot sing the same pitches they will often make at least some attempt to sing the same pitch classes. Note that a pitch class is not defined by any arbitrary range of frequencies: a given pitch ‘A’ could be assigned to 440Hz or 444Hz or some other frequency, but our perception of attunement will detect distinct flaws if the  $1:2^n$  relationship is not maintained in relation to a chosen frequency (in the former case, for example, between versions of the pitch class ‘A’ at 110Hz, 220Hz, 440Hz and so on).

<sup>19</sup> It is much easier for a musician to develop a clear notion of what a consonant interval should sound like, especially in an idealized form, rather than a dissonant interval; therefore, the construction of an attunement typically uses consonant intervals, from which the particular form of dissonant intervals will emerge. This does not mean that the attunement is disinterested in dissonant intervals, for many attunements are in fact distinguished precisely by the form and particular distribution of dissonant intervals, which can be of tremendous consequence in musical applications.

concerns with acoustic measuring devices—in addition to the monochord he uses something called the *helikon*, plus another instrument derived from this that will be of particular interest—is the removal of possible error from the system. (How he can judge that error is a point I return to below.) At times this concern can verge on the obsessive, as Barker demonstrates with respect to Ptolemy's attention to interacting variables of string length and tension that result from using a dividing bridge that displaces the string from the horizontal: this is a feature that, 'from a practical point of view...is essential if the string is to come into firm contact with the bridge', and 'is not a requirement that 'pure theory' would recognize, since from the point of view of mathematical geometry, [a] line EH will touch a bridge at [point] K perfectly satisfactorily if it is exactly the same height as the others [that mark the endpoints, E and H]'. (pp.197–8) Barker's emphasis on Ptolemy's practical concerns is significant, as it is precisely this type of attention to experimental design that convinces him (and, it should be added, this reviewer) that Ptolemy's measuring instruments were not merely fanciful geometrical sketches that never saw production or use. Furthermore, it is important that we appreciate what this type of attention suggests about Ptolemy's priorities as an investigator:

One of Ptolemy's main concerns...is to ensure that none of the distortions of pitch affecting other instruments is allowed to creep in at any stage. It is not, for the most part, the theoretical credentials of the geometrical plans of his devices that are at stake, but the practical reliability of the concrete pieces of apparatus themselves. He sets out by explaining how the monochord, and similar instruments, can be used to test the reliability of their own material components—an interesting early occurrence of the notion of a self-correcting apparatus. Later, as modifications and new instruments are introduced, Ptolemy invariably explains why it is that they bring no uncontrolled variables with them, or how such distortions can be eliminated in practice. His thorough examination of even very minor issues leaves few of these practical problems unresolved.... (p. 226)

Despite this acute focus on controlled variables, Ptolemy remains guilty of a sin of omission: his failure to discover a 'tension law' for strings that Vincenzo Galilei would later trip over, demonstrating that consonant intervals could be determined by weights applied to strings of equal length, where the ratios of weight are the inverse squares of those for variable length where tension is held constant. Or should the previous sentence have begun with 'because of' instead of 'despite'? Vincenzo's bold stroke of success with the tension law is often pointed to as his greatest triumph in experimental acoustics, not to mention his *coup de grâce* to the Pythagorean ratios; and yet one will search in vain through Vincenzo's acoustic manuscripts to find any evidence of the kind of experimental controls involved in isolating the effects of string tension that are detailed in Ptolemy. If anything, the textual evidence recording Ptolemy's attempts to minimize the experimental noise of tension would suggest him to be the greater experimentalist in this regard.<sup>20</sup>

<sup>20</sup> I am, of course, making some sport of the legend of Vincenzo, partly because the attention given to the tension law overshadows the very interesting—and much better documented—experimental work he did with strings composed of different materials. See his 'A Special Discourse Concerning the Unison' in this regard; the tension law is unveiled in 'A Special Discourse Concerning the Diversity of the Ratios of the Diapason', along with a fascinating empirical numerology. Both of these works may be found in translation with the original Italian on facing pages in Palisca. (note 15)

Of course, in a work that uses ‘scientific method’ as part of its title, we might expect a concerted effort to find the smoking gun, the experimentally-refuted hypothesis (whether it is anachronistic to associate this with Ptolemy’s *hupotheseis* is, to be expected, one of the issues at stake). There may still be philosophers of science whose pulse will quicken at such a prospect, but Barker must cautiously address Ptolemy’s intentions:

The question whether Ptolemy really used any instruments at all, or intended his readers to do so, has already, I think, been settled with some certainty.... It still remains possible, however, despite his explicit pronouncements, that like most of his predecessors, Ptolemy conceived the presentation of propositions in perceptible form more as a strategy for displaying the truth of his conclusions than as a way of submitting them to experimental tests. This issue, it seems to me, is much the most important we shall be facing here. (p. 230)

The core issue is the distinction between demonstration and experimentation, for which Ptolemy gives us no ready terminology. Barker begins with Ptolemy’s reference to the ratios of the consonances following their theoretical derivation: ‘but now it would be a good thing to demonstrate [*apodeixai*] the clear truth of the ratios that have already been set out, so that we may have their agreement with perception established beyond dispute’. (16.29–31) Barker comments on Ptolemy’s locution:

The core sense of the verb *apodeixai* is ‘to display’, ‘to exhibit’, and especially in philosophical or scientific contexts it is regularly used to mean ‘to prove’, ‘to show by argument’. An *apodeixis* can be the ‘exhibition’ or ‘exposition’ of something, but in technical writings it is the commonest word for ‘proof’, especially one set out in strict logical form. It carries not the least suggestion of testing a proposition or trying out a hypothesis. (p. 231)

In this case,

we should not be surprised by these indications that the procedure constitutes a ‘display’ or ‘proof’, and not a test. The ratios of the concords had been known for centuries.... It would be strange, in fact, if Ptolemy showed signs of construing his demonstration as some sort of test, such that if the result came out wrong on some occasion, that would cast real doubt on the correctness of the ratios. Their values were by now so well established...that the only proper response to an inappropriate result would be to assume that the apparatus had been wrongly set up, and to look for the fault. (p. 232)

With conventional wisdom’s insistence on the mystical status of the Pythagorean ratios, it is refreshing to read the work of a classicist who can remind us that issues of instrument calibration are no Orphic mystery. But Barker does find Ptolemy to go further in the realm of empirical investigation; and while it is not possible to do justice to the fine detail of Barker’s account here, there are some crucial features that should be brought to the attention of historians of science.

One key theme of Barker’s account is the way in which Ptolemy’s preferences in, description of, and directions for using apparatus appear to be directed to a community of researchers who may be expected to reproduce or possibly test the relationship between Ptolemy’s theoretical claims and their empirical results. The *kanon* or the *helikon* might not be the TEA-laser, but the detailed considerations of

both construction and application reveal the stake such instrumentation holds in Ptolemy's *Harmonics*. Even after ensuring that the *kanon* or monochord has been designed with the utmost care to yield reliable results, Ptolemy will insist on using the device in such a way that the pitches constituent of the interval under examination can be heard either simultaneously or in rapid succession, rather than recommending a technique for manipulation of the device which precludes this possibility. As Barker notes, 'this fact gives some support to the view that he intended serious students of the subject to 'display' the ratios of the concords [consonant intervals] to their ears in practice, even if the operation is not to be understood strictly as a test'. (p. 233) The importance that Ptolemy attaches to the actual performance of his attunements is likewise reflected in his preferences for instrumentation, as we discover with respect to the limitations of the monochord, however optimally it may be deployed. Barker observes that, 'no other Greek writer on mathematical harmonics, so far as I know, shows any sign of appreciating the need to present attunements for the critical ear to assess, not as bare structures or scales, but at work in the melodies whose foundations they are alleged to be'. (p. 206) To this end, Ptolemy turns his attention first to the *helikon*, a multi-stringed device that will make such a musical context available for acoustic investigation, but then apparently designs a new device that departs not only in certain features from the *helikon* but in its set-up procedures as well. The procedure appears somewhat awkward, but Barker finds uncommon sense in this:

from the perspective of someone who is actually setting up such an instrument for use, step by step, this is the right order. We need to know the practical function of each element in the figure as we proceed, in order to understand what it is, physically speaking, that we are required to do.... Thus while the account of the *helikon* reads like a passage from a treatise in geometry, subsequently given a concrete application, the second account is more like a set of instructions from a 'Build-your-own-instrument' manual.... Ptolemy intended that the instrument should really be made. (p. 210)

And why? Barker contends that this is not just a matter of being able to enjoy the fruits of an attunement on a device that may simultaneously purport to demonstrate its rational principles; he suggests that the performance—whether it be on an experimental instrument like the *kanon* or a conventional instrument like the *lyra*—may in fact challenge the principles of attunement it has been asked to realize. In the case of one such assessment, of the ditonic diatonic, he writes:

[Ptolemy] found that it came close, but that there were good, empirically grounded reasons for admitting that the fit was not exact.... [H]e was prepared to accept, at least in this special case, that the results of his empirical investigations were inconsistent with the predictions of his *hupotheseis*, in their original, unmodified form. The *hupotheseis* are not therefore abandoned, but they are undeniably bent; perceptual tests have been permitted to exercise the right of adjudication which Ptolemy's declared methodology assigned them. (p. 241)

Ptolemy's interest in the ditonic diatonic is associated with attunement of conventional, non-experimental instruments, the *lyra* and *kithara*, the subject of a chapter in Book I of the *Harmonics*. Barker finds this discussion of particular

interest, as it rounds out our picture of Ptolemy's experimental considerations in a striking way:

What stands out most prominently in this important chapter is the absolute requirement that the procedures be conducted in practice. There are some purely argumentative steps, as we have seen...but the demonstration as a whole cannot work by argument alone. It hangs crucially on the ear's judgement.... Whether anybody actually went through the whole series of operations or not, the presence of these procedural recipes in the text *by itself* puts Ptolemy's contentions genuinely at risk. The procedures are unquestionably empirical, and if the results fail to match Ptolemy's predictions his analyses must be rejected. Here, it seems to me, we have a very strong case indeed for ridding the word 'tests' of its cautionary inverted commas. These are tests in the fullest sense; and one may reasonably guess that it was partly through procedures of the sorts described here that Ptolemy reached his diagnoses of this set of attunements in the first place. (pp. 247–8)

Barker, as has already been noted, purposefully keeps his attention close to the text at hand (albeit, with suitable references throughout to the context of Greek harmonics); nonetheless, this in no way prevents us from developing some appreciation of what Vincenzo and Kepler thought all the fuss was about, or from reading their work with much greater sensitivity to its intellectual context. Readers interested in a broader range of topics concerned with music and the history of science would do well to peruse the Kassler collection, which offers an enjoyable and often intriguing variety of articles that covers the gamut from the Pythagorean to the Popperian, with many stops in-between that will meet the interests of a diverse audience. Here we will sometimes find the usual suspects caught in unusual (or, at least, relatively unfamiliar) scientific pursuits, along with the odd unusual suspect from a seemingly limitless resource of British eccentrics in the history of science. As is often the case with such publications, one catches oneself at times noting a possible connection between the articles that one might wish to see explored further by the author herself, but Kassler has generally done a good job of arranging the articles in a meaningful way while still offering the more cavalier reader the possibility of diving impetuously into whatever title snares one's curiosity. Indeed, this reviewer found himself strangely drawn to an article entitled, 'On the Stretch: Hobbes, Mechanics and the Shaking Palsy'—not necessarily a few of my favourite things—and discovered an absorbing account of the musical prospects of Hobbes' mechanics. (pp. 83–124) One is reminded here of N. M. Swerdlow's evocative phrase concerning Kepler's music of the spheres: 'while Kepler's laws eventually found their Newton, his harmonies never found their Bohr'.<sup>21</sup> Without wholly succumbing to the fashion for alternative histories, it is at least tempting to wonder how they might have fared had they found their Hobbes.

Like the members of the Académie Royale, one is not always convinced of the scientific merit of various music-related pursuits. When I read William 'Trinity' Jones' account of *materia musica* in Kassler's earliest article in the collection, 'Music as Matter in Motion', I am reminded less of Feynman than of my Fowler's:

<sup>21</sup> See N. M. Swerdlow, 'Kepler and the Theory of Music', *Journal for the History of Astronomy*, 7 (1976): 198–201.

It is very usual to make a stop, equivalent to a Comma, after three fourths of the first Bar; another stop, equivalent to a Colon or Semicolon, after three fourths of the second Bar: the first clause containing the first or principal subject, the next a second or subordinate Subject. Sometimes the first comma is found at three fourths of the second Bar: and another stop at the correspondent part of the fourth Bar; or...[etc.] (p. 209)

There is no impropriety here, for the lexicon of grammar and rhetoric was something of a commonplace in eighteenth century analysis of music, if not necessarily of matter. Still, it is a characteristic shared by all three authors whose works have been under review here that they do not stoop to conquer, demanding of their audience an unmeasured response. The books of Barker, Kahn and Kassler testify to a wealth of fascinating subject matter that attracts the finest scholarly minds; and if works such as these cannot yet provide a definitive response to the question of what science has to do with music, then it is the mark of a fertile field that, one hopes, will continue to draw the interest of the academy.