GNŌMONIKĒ TECHNĒ:
The Dialer's Art and its Meanings for the Ancient World

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Abstract: *Gnōmonikē Technē*, the art of gnomonics, was a recognized branch of applied mathematics in Greek antiquity. The variety of ancient sundials that survive show us that ancient dialers were prolific and inventive. This paper places ancient gnomonics in scientific and cultural perspective and offers an overview of ancient dial types.

Key words: sundials, ancient Greek astronomy, ancient Greek mathematics, Roman science, gnomonics, sphairopoiïa, Geminus, Vitruvius

Dedicated to Woody Sullivan, in memory of Themistagoras, son of Meniskos

1. INTRODUCTION

When Woody Sullivan, Jim Bell and Bill Nye conceived a method of placing a sundial on the surface of Mars—by using parts of the lander that had been designed for a different purpose—they had more in mind than telling time (see Sullivan and Bell, 2004). The motto on the sundial, "Two worlds, one Sun", speaks of the symbolic value of the device. Thus, Woody's Martian sundial (for relevant details of this see the web site http://planetary.org/rrgtm/marsdial/index.html) has less to do with telling time than with saying something about *us*. In antiquity, dialing was no less intricately connected with the conception of the place of humanity in the cosmos.

The Greeks had a name for this science: *gnōmonikē technē*, the art of gnomonics. The Greek noun *gnōmōn* (which we still use today) refers to the stylus or index that casts the shadow. It descends from a verb, *gignōskō*,

W. Orchiston, (ed.), The New Astronomy: Opening the Electromagnetic Window and Expanding our View of Planet Earth, 273-292.

which means *learn*, *perceive*, *judge* and, in past tenses, simply *know*. Before it was a part of a sundial, a *gnōmōn* therefore meant *someone who knows*, *a judge*—but also *a carpenter's rule*, and hence sometimes, metaphorically, *a rule* of life. (Woody's motto on the Mars dial is also an apt rule of life. It may be paraphrased as: "Think cosmically, act globally.") According to Liddell, Scott and Jones (1996), a *technē* is an *art* or *craft*, that is, something requiring study and devotion. Hence the aphorism attributed to Hippocrates: "life is short, art (*technē*) is long." As we might infer from its use in this example from medical writing, *technē* can be used to indicate *a science* or *a system of making or doing* something.

2. GNOMONICS AS A BRANCH OF APPLIED MATHEMATICS

Above all else, dialing is a branch of applied mathematics. Geminus, a Greek astronomical writer of the first century B.C., has left us a classification of the branches of mathematics, which is the most detailed discussion of this subject surviving from antiquity. Geminus' discussion was in a book, now lost, that treated the history and philosophical foundations of mathematics. Its title was perhaps *Philokalia* (*Love of the Beautiful*). Geminus' discussion of the branches of mathematical learning has been preserved by Proclus, who quotes it at length in his commentary on Euclid (see Proclus, 1970: 31-35; for discussions, see Evans, 1999; Heath, 1921, Volume 1: 10-18; and Tannery, 1887: 38-52).

According to Geminus (see Figure 1), mathematics is divided first of all into the pure and the applied. Pure mathematics is concerned with mental objects only, such as number in the case of arithmetic and ideal lines and planes in the case of geometry. For the Greeks, 'arithmetic' means number theory of the sort associated with the Pythagoreans, and not the routine computation taught to children. Under applied mathematics, Geminus ranges six arts: practical calculation, geodesy, harmonics, optics, mechanics and astronomy. Practical calculation (which the Greeks called *logistic*) is the elementary computation that is taught in the schools. It is an offspring of arithmetic, in the same way that geodesy is an offspring of geometry. Harmonics, or the theory of concordant sounds, is an application of number theory, in the same way that optics is an application of the geometry of straight lines. Under mechanics, Geminus lists four subdivisions: military engineering (the making of catapults and so on), "wonderworking" (the making of automata operated by gas or fluid pressure, such as the gadgets described by Hero of Alexandria), the study of equilibrium and centers of gravity (pioneered by Archimedes), and "sphere-making," or *sphairopoiïa* (which has to do with making mechanical images of the heavens, such as celestial globes). According to Geminus, astronomy has three subdivisions: gnomonics (our subject—the making of sundials), meteoroscopy (involving specialized instruments such as the armillary sphere) and dioptrics (devoted to the measuring instrument called the *dioptra*).

Figure 1. Geminus' Classification of Mathematics

- Pure Mathematics
  - Arithmetic
  - Geometry
- Applied mathematics
  - Practical calculation
  - Geodesy
  - Harmonics
  - Optics
    - Optics proper (straight rays)
    - Catoptrics (mirrors)
    - Scenography (perspective)
  - Mechanics
    - Military engineering
    - Wonderworking
    - Equilibrium and centers of gravity
    - Sphere-making (*sphairopoiïa*)
  - Astronomy
    - **Gnomonics**
    - Meteoroscopy
    - Dioptrics

It is remarkable that we still possess, or know of the existence of, mathematical treatises on every one of these topics. So it is clear that Geminus is describing, not merely a conceptual division of applied mathematics, but actual genres of mathematical writing. *Gnomonics*, then, is a branch of applied mathematics, in which the geometer could show great skill, perhaps by inventing a new kind of dial.

3. A SAMPLE OF ANCIENT DIAL TYPES

The Greeks dialers were very inventive. The sheer number of ancient dial types proves that gnomonics was always about much more than practical time-telling. A fascinating list of dial types and their inventors has been left by Vitruvius (*On Architecture*, ix, 8.1; commentary in Soubiran, 1969), a Roman writer on architecture who lived in the age of Augustus:

> The semicircular form, hollowed out of a square block, and cut under to correspond to the polar altitude, is said to have been invented by Berosus the Chaldean; the scaphe or hemisphere by Aristarchus of Samos, as well as the disk on a plane surface; the arachne by the astronomer Eudoxus or, as some say, by Apollonius; the plinthium or lacunar, like the one placed in the Circus Flaminius, by Scopinas of Syracuse; the πρὸς τα ιστορούμενα, by Parmenio; the πρὸς παν κλιμα, by Theodosius and Andreas; the pelecinum, by Patrocles; the cone, by Dionysodorus; the quiver, by Apollonius.

Besides these dial types, Vitruvius mentions also the conarachne, the conical plinthium and the antiborean, without attributing them to particular writers.

It is clear from Vitruvius' remarks that gnomonics comprised a sizable specialized literature. The inventor of a new type of dial might announce it by writing a short, specialized treatise, as well as by actually making a dial for display. None of this literature has come down to us. The only substantial accounts of gnomonics that have been preserved are Vitruvius' short and disappointing summary and Ptolemy's more technical account of the theory of projection in *On the Analemma* (Ptolemy, 1898-1954, volume 2; for a discussion, see Neugebauer, 1975: 839-856). For this reason, the dial types mentioned by Vitruvius cannot all be certainly identified with extant dials in museum collections (e.g. see Gibbs, 1976: 59-65). Nor, of course, can we be very confident of Vitruvius' attributions to particular inventors. This reflects the agonistic character of ancient Greek society, in which

> potter is angry with potter, carpenter with carpenter,
> beggar is jealous of beggar, and bard of bard
> (Hesiod, *Works and Days*, lines 25-26).

Mathematicians were as careful to see that they received credit for a new theorem, and no doubt dialers wanted credit for a new dial. Greek and Roman writers are fond of attributing, whenever possible, any invention or discovery to a particular person, even when, from our perspective, the evidence looks rather shaky.[1]

Nearly 300 Greek and Roman sundials have survived from antiquity; 256 of these are listed in Gibbs' book (1976) and others in papers by Arnauldi and Schaldach (1997), Catamo, *et. al*. (2000), Locher (1989), Pattenden (1981) and Rohr (1980).[2] From the theoretical point of view point, the simplest variety is the spherical dial—Vitruvius' scaphe. The shadow-receiving surface is the interior of a hemisphere. The tip of the gnomon lies at the center of the spherical surface. Since the dial is merely the inverted image of the celestial sphere, the theory governing the placement of the hour lines, as well as the equator and tropics is very simple. However, since the Sun cannot be found at just any place on the celestial sphere, but must remain between the tropics, an entire hemisphere of stone is not required. The lower part of the south face of the dial can be cut away (corresponding to the part of the sky above the tropic of Cancer). This is the dial that Vitruvius refers to as a "semicircular form, hollowed out of a square block, and cut under to correspond to the polar altitude."

Figure 2 shows an idealized view of this kind of dial. Eleven hour curves serve to indicate *seasonal hours.* The period from sunset to sunrise consists always of twelve hours, all equal to one another. Similarly, the night is divided into twelve equal hours. In the summer the day hour is long and the night hour is short, while in winter the opposite is true. The *equinoctial hour* that we use today (one twenty-forth part of the whole diurnal period) is a seasonal hour evaluated on the day of equinox. Although Greek astronomers did use the equinoctial hour when they needed a uniform unit of time for precise calculation, the seasonal hour was the only one used in everyday life. All surviving Greek and Roman sundials are marked in seasonal hours.[3] The dial in Figure 2 is also furnished with three *day curves*, indicating the track of the shadow's tip on (from top to bottom) winter solstice, equinox, and summer solstice.

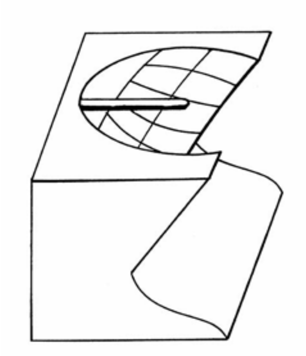

Figure 2. Principle of the spherical sundial with cut-away south face.

The gray stone dial from Pompeii shown in Figure 3 is of this same general type. The broken-out hole at the top originally carried the gnomon. It is very rare to find ancient dials still carrying gnomons. Iron gnomons would have rusted away over the centuries, and bronze ones must often have been appropriated and the metal put to some other use. A peculiar feature of this dial and a number of others from Roman sites is that the three day curves do not correspond to the equinoxes and solstices. On the Greek prototype of Figure 2, since the gnomon tip is at the center of the spherical surface, the equator curve must be equidistant from the two tropics. But this is not the case with the dial of Figure 3, on which the three day curves are just arbitrary circles of constant declination. They perhaps served a practical purpose for the dialer: each circle of constant declination is divided into twelve equal arcs by the horizon and eleven hour curves. Putting on the day curves was therefore a step toward the construction of the hour curves. In any case, the dial of Figure 3 can be used to tell the time of day, but not the season of the year. This was not necessarily a mistake—the dialer and his customers may have been interested only in the time of day—but it does represent a falling away from the quality of the earlier Greek dials, most clearly exemplified by a large number of the first century B.C. and earlier found on Delos. For a comparison of Delos and Pompeii dials see Gibbs (1976: 90-92).

Figure 3. A First Century A.D. spherical dial from Pompeii, 32 × 40 cm, Gibbs No. 1020 (courtesy: Soprin-tendenza Archelogica di Pompei, Inv. 34221).

To judge by the numbers preserved, the most common dial was of the *conical* type, which Vitruvius attributes to Dionysodorus. In a conical dial, the shadow-receiving surface is the inner surface of a cone. Typically, the conical surface was cut into a roughly rectangular slab of stone, as with the dial shown in Figure 4. The stone-working involved in making a conical dial was easier than that required for a spherical dial. But, by compensation, the theory was more complicated: it was necessary to project the celestial sphere onto a conical surface.

Large numbers of *plane* dials have also been preserved. In the dial of Figure 5 we see the typical form of a horizontal plane sundial. The central line is the meridian. The upper curve is the shadow track for summer solstice; the horizontal straight line, the shadow track for equinox; and the lower curve, for winter solstice. The hole where the metal gnomon was inserted is visible just above the summer solstitial curve. The eleven more or less vertical lines represent the hours. A photograph of the extant fragments of this dial is included in Gibbs (1976: Plate 55).

Figure 4. Conical dial found near Alexandria at the base of Cleopatra's needle, 40 high × 43 cm wide. The Greek numerals labeling the hour lines are an unusual feature and are probably Byzantine additions to the original Ptolemaic dial. Gibbs No. 3086 (British Museum No. 1936 3-9.1. Photograph courtesy of the British Museum).

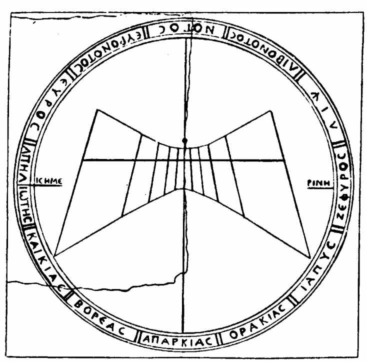

Figure 5. A horizontal plane sundial found near Rome. The extant portion of the dial is approximately the left half, inside the wavy line, and measures 35 cm × 54 cm. The remainder of the illustration is a restoration. Gibbs No. 4008 (illustration after Diels, 1924).

'Furniture' is a term used by modern dialers for auxiliary features of a dial that are not directly connected with its time-telling function. The dial shown in Figure 5 carries an interesting bit of furniture: the names of twelve winds were engraved, in Greek, in a circle around the perimeter. Notos (the south wind) is at the top and Zephyros (the west wind) is at the right. In popular Greek and Roman thinking, winds were sometimes personified as minor gods. Thus, on the Tower of the Winds in Athens, each of the eight vertical faces of the structure is graced by an individually-designed sundial and by a relief sculpture of the personified wind associated with the direction towards which the dial faces (for an illustration, see Evans, 1998: 131). In scientific treatises on winds (Pliny, *Natural History*, ii, 114-132; Theophrastus, *De Ventis*; see also Taub, 2003: 107, 149), each wind was analyzed according to its properties (hot or cold, moist or dry), as well as the time of year in which it was wont to blow. However, on sundials, wind names are often merely a poetic way of indicating a direction on the horizon.

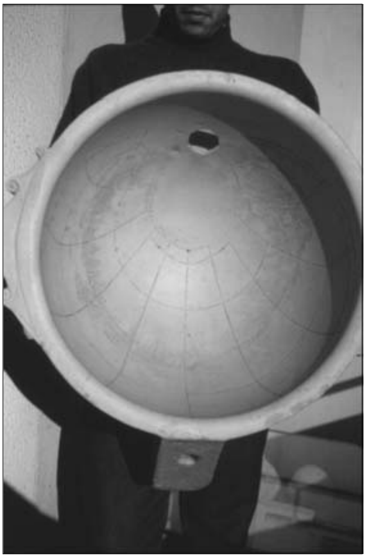

Figure 6. A spectacular First or Second Century A.D. Greek dial from Roman Carthage. Interior diameter 49 cm (photograph by Denis Savoie of a cast of the original dial).

One of the most spectacular ancient sundials preserved from antiquity is shown in Figure 6. This dial, found at Roman Carthage before the Second World War, was acquired by the Louvre in 1999, and is now on display there (Département des Antiquités Grecques, Étrusques et Romaines, MNE 1178; see Savoie and Lehoucq, 2001; Pasquier and Savoie, 2000). It is of marble, imitates the form of a fancy serving vessel or silver goblet, is decorated with oak leaves and acorns in relief, and carries two ornamental handles. In use, the vessel is mounted six or seven feet off the ground and is tipped (to correspond to the latitude) with the bowl facing downward at an angle. The bottom of the vessel is pierced by a hole through which sunlight shines. It is the spot of light falling on the interior network of curves that indicates the hour. The original hole was smaller than the opening in the marble, for there is a recess for a fitted metal plaque which must have carried a small hole. This dial is of the type called a 'scaphe with eyelet' by Savoie or 'roofed spherical dial' by Gibbs. It is essentially a hemispherical dial with the gnomon tip located on the surface of the sphere—which leads to hour curves that are rather complicated from a mathematical point of view. Finally, this dial carries an interesting bit of furniture: seven declination curves, for the dates of the Sun's entry into successive zodiac signs. These are labeled in Greek with the dates expressed in terms of the Julian calendar.

These are far from exhausting the types. The πρὸς παν κλιμα mentioned by Vitruvius in the quotation above was a dial that worked "… for every latitude." And, as Vitruvius (*On Architecture*, ix, 8.1) tells us, "Many have also left us written directions for making dials … for travelers, which can be hung up." A number of ingenious portable dials have, indeed, been found (e.g. see Price, 1969). In some cases, the sundial was combined with a gearwork mechanism that enabled the user to keep track of the place of the Sun and the Moon in the zodiac (Field and Wright, 1984).

4. GNOMONICS AND SPHAIROPOIÏA

Gnomonics had intimate links with the theory of the celestial sphere, and hence also with *sphairopoiïa*, another of Geminus' branches of applied mathematics. *Sphairopoiïa* is the art of making mechanical images of the heavens. Celestial globes and armillary spheres were two of the most common examples of this art. In the armillary sphere, the sky is represented not as a solid sphere, but by a network of rings (the Latin word *armilla* signifying an armband or bracelet). These rings embody the most important circles of the sphere: ecliptic, equator, tropics, arctic and antarctic circles, as well as the colures. None of these delicate constructions have survived from antiquity, but they are mentioned by ancient Greek writers who refer to them as *krikotai sphairai*—"ringed spheres." There are two spectacular illustrations of armillary spheres preserved in ancient art—a ceiling painting in Stabiae, near Pompeii (see Arnaud, 1984: 73; Carmodo and Ferrara, 1989: 67-68) and a mosaic in Solunto, near Palermo (Von Boeselager, 1983: 56-60 and Tafel XV). Figure 7 is a Renaissance illustration of an armillary sphere, which scarcely differs from the ancient prototypes.

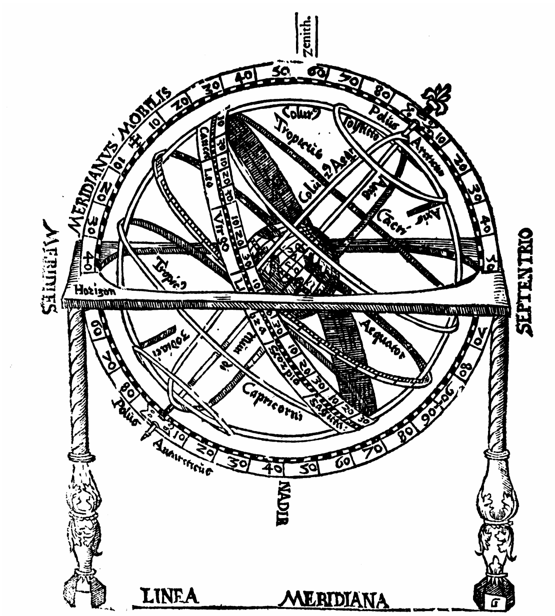

Figure 7. A Renaissance illustration of an armillary sphere (after *Cosmographia* ..., 1584) (photograph courtesy of the Special Collections, University of Washington Libraries, Negative UW18183).

Now, just preceding his list of sundials and their inventors, Vitruvius (*On Architecture*, ix, 7) gives us a fascinating look at how they can be designed. He describes a geometrical construction called the *analemma*. In Greek, *analemma* refers to a preliminary, supporting construction, which serves as an aid to the principal task. In everyday life, *analemma* could refer to 'scaffolding' or 'retaining walls', or even to a 'sling' for a wounded arm. In a graphical construction, an analemma plays a role analogous to that of a lemma in a logical proof. The analemma that Vitruvius constructs is shown in Figure 8.

The diagram lies in the plane of the celestial meridian. *AB* is the gnomon, which casts its shadow upon the ground *BT*. *EAI* represents the theoretical horizon plane. About *A* as center, describe circle *NBI* to represent the celestial sphere. Draw the axis *ZAQ* of the universe, at an angle *QAI* from the horizon. (This angle is equal to the latitude of the observer). The celestial equator is *NAF* and the two tropics (seen from the side) are *LPG* and *MOH*, located 24º above and below the equator. It is now instructive to compare Figure 8 with Figure 7. We see that *the analemma of Vitruvius is a side view of an armillary sphere.*

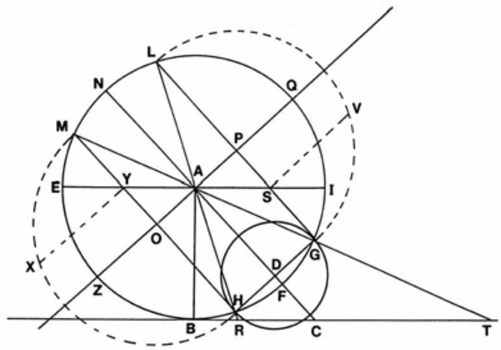

Figure 8. The analemma described by Vitruvius.

If a semicircle of the tropic of Cancer is folded down into the plane of the meridian, it becomes semicircle *LVG*. If we imagine standing this semicircle back up so that it is perpendicular to the plane of the diagram, line *SV* will lie in the plane of the horizon. *V* is therefore the sunset point—the location of the Sun at sunset on summer solstice. Arc *LV* therefore represents the six seasonal hours between noon (*L*) and sunset (*V*) on summer solstice. Sundial construction therefore begins with a division of arc *LV* into six equal parts.

In the same way, the daytime arc *MX* of the folded down tropic of Capricorn *MXH* must be divided into six equal parts. Unfortunately, Vitruvius (*On Architecture*, ix, 7.7) does not bother to tell us how to construct a sundial—lest he should "… prove tiresome by writing too much." At the end of his list of dial types and their inventors, he simply remarks, "Whoever wishes to find their projections can do so from the books of these writers, provided he understands the figure of the analemma … (*On Architecture*, ix, 8.1). Sadly, the end of Ptolemy's treatise on the analemma appears to be missing. So, in neither of the extant discussions of analemmas do we find an actual application. However, modern scholars have shown a number of ways in which the dials can actually be constructed (e.g. see Evans, 1998: 135-140).

Another interesting connection between gnomonics and *sphairopoiïa* is the occasional use of a miniature celestial globe as an ornament for the tip of the gnomon. We know that gnomons of monumental size sometimes ended in a spiked ball. This was true of the great sundial (discussed below) that

Augustus set up on the Field of Mars in Rome. The use of a sphere at the top of the gnomon aided the person reading a sundial to spot the true location of the shadow tip. Now, only three intact celestial globes have come down to us from antiquity. One of these, in Mainz, is 11 cm in diameter, is of copper alloy and is figured with constellations, the principal celestial circles and the Milky Way, as well as individual stars. The sphere has a small square hole in its top and a larger round hole in its bottom, which suggest that this globe was meant to fit over the tip of a gnomon (see Künzl, 2000).

In standard gnomonics, one places the tip of the gnomon at the center of the universe, as in Figure 8. Point *A* is simultaneously the tip of the gnomon, the entire Earth (which may be considered a mere point), and the center of the celestial sphere. In *Almagest*, i, 6, Ptolemy cites this practice as common knowledge, as part of his proof that the Earth is a point in respect to the celestial sphere: "Gnomons placed in any part of the Earth can play the role of the Earth's true center." Thus, placing a small celestial globe at the tip of a gnomon is not a mere whim, but reflects an understanding of a basic principle of gnomonics—that the tip of the gnomon is to be treated as the center of the Universe.

The quality of ancient sundials varies enormously. The workmanship varies from crude to exquisite. Some dials are engraved in marble and furnished with ornaments such as Lions' paws (e.g. Gibbs, Numbers 2017, 3027 and 3056), or are supported by a figure of Atlas (e.g. Gibbs, No. 1034). Others are quite plain, and were cut from cheaper stone, then covered with stucco. This is true, for example, of a number of the Pompeii dials (including Gibbs, No. 1026), which must have been the products of mass production.

In the same way, the time-keeping accuracy (both within the day and within the year) varies greatly from one dial to another. Some gnomonicists must have been skilled in the use of the analemma, which is suggested by the survival of construction marks on a few ancient dials. For example, the dial of Figure 6 carries several small holes situated on the declination circles, which, when connected, approximately determine a circle (see Savoie and Le Lehoucq, 2001: 32). This probably represents the *menaeus* circle mentioned by Vitruvius in the course of his construction of the analemma—the small circle with diameter *HG* in Figure 8. The *menaeus* circle is used precisely for establishing lines of a given declination. The dialer who made the this dial was a skillful gnomonicist, but even he had his limitations, as shown by the irregular, distorted shapes of the hour curves closest to the small hole. The theoretical construction of the hour curves on this ambitious type of dial is complicated. So it is possible that the dialer calibrated the hours, not by theory, but by taking time readings from an already-completed dial of simple construction.

5. SUNDIALS IN THE PUBLIC CONSCIOUSNESS

As we have seen, Vitruvius ascribes the invention of one kind of sundial to Eudoxus (ca. 360 B.C.), which does not seem impossible. Herodotus (ca. 430 B.C.) already mentions the gnomon in his *Histories* (ii, 109), saying that Greeks learned about it from the Babylonians. In the same passage, Herodotus also says that the Greeks got the twelve-hour day and the *polos* (perhaps a concave sundial) from the Babylonians. But the significance and accuracy of this statement have been much debated. Diogenes Laertius (*Lives and Opinions of Eminent Philosophers*, ii, 1) puts the first use of the gnomon by the Greeks much earlier, claiming that Anaximander (sixth century B.C.) set one up at Sparta. Of course, a gnomon can be used for purposes other than telling the time of day, such as for demonstrating solstices and equinoxes. We have no way of knowing when the first true sundials, calibrated in seasonal hours, were developed. But textual mentions of sundials, as well as the archaeological evidence, suggests that sundials did not become common until the third century B.C. After that, there must have been an explosion of interest, as new dial types were invented, and dials became increasingly common in public places.

One of the oldest approximately-datable dials is a double conical dial, with separate north- and south-facing dial faces (the north-facing one likely representing Vitruvius' antiborean type). This dial is currently in the Louvre (MA 2820), and is No. 3049 in Gibbs' catalogue (1976). It was found at Heraclea-by-Latmus, near Miletus (Turkey), and carries a dedication in Greek to King Ptolemy. This is most probably Ptolemy II Philadelphus, who ruled Egypt 281-246 B.C., and whose possessions included Heraclea for a time (and this is why the Louvre catalogue dates this dial to 277-262 B.C., "… by the historical context of the inscription."). This inscription includes the name of the donor, who presumably paid for the dial—a certain Apollonius the son of Apollodotus—and concludes: "Themistagoras the son of Meniskos, from Alexandria, made … [the sundial]." This Themistagoras, whose craftsmanship is excellent, is the earliest gnomonicist from whom we possess datable work. I suggest that the next interplanetary gnomonics mission should carry a dedication to Themistagoras.

Although sundials spread first through the Greek world they also became known to Roman society in the third century B.C. According to Pliny (*Natural History*, vii, 213), the first public sundial in Rome was set up on a column during the First Punic War, having been brought to Rome by the consul Manius Valerius Messala after his capture of Catania in Greek Sicily (263 B.C.). Pliny remarks that, although the lines on this sundial did not agree with the hours, the Romans continued to use it for ninety-nine years, until it was replaced by a better one. All good gnomonicists of course knew that sundials had to be designed for specific latitudes. But third-century Romans were as yet unschooled in gnomonics; besides, the dial stolen from Catania was probably intended to serve more as trophy than as timekeeper. And yet, the case has a number of parallels, for modern analyses show that not all ancient dials were designed for the latitudes of the sites at which they were later recovered. For example, according to Savoie and Lehoucq (2001), the beautiful dial shown in Figure 6, which was found at Carthage (latitude 37º), was actually designed for a latitude near 41º (corresponding to Rome or the Hellespont). Even today, it is notorious that sundials in garden shops, designed for a generic 45º, are often sold to buyers innocent of latitudinal concerns.

By the first century B.C., sundials had become common enough in the Greek world that writers on geography or astronomy could expect their readers to be familiar with these instruments, as well as with celestial globes. Assuming such familiarity, the writer was able to appeal to these instruments in illustration or argument. In the introductory book of his *Geography*, Strabo assures his readers that they need not be experts in astronomy, but warns they should not be so simple or lazy as never to have seen a globe and the circles inscribed upon it, or to have examined the positions of the tropics, equator and zodiac. As Strabo (*Geography*, i, 1.21) points out, this is the sort of background acquired in an introductory mathematics courses. And when referring to the daily revolution of the heavens, he remarks (*Geography*, i, 1.20) that this revolution is manifest most particularly from sundials.

A good example of the elementary astronomy curriculum that Strabo had in mind is provided by the *Introduction to the Phenomena* of Geminus, whom we met above as the author of the lost *Philokalia*. The *Introduction to the Phenomena*, which has come down to us more or less intact, was written for beginners and provides a patient and graceful introduction to many topics of Greek astronomy. On several occasions, in order to make a convincing astronomical point, Geminus appeals to objects that his reader is likely to be familiar with, including celestial globes and sundials. For example, in discussing the fact that the Sun's declination scarcely changes while it is approaching and then receding from the tropic, Geminus remarks, "This is clear, too, from the sundials, for the tip of the gnomon's shadow remains on the tropic curves for about 40 days." (Geminus, *Introduction to the Phenomena*, vi, 32; see also i, 38). Geminus expected his students and readers to be familiar enough with sundials to accept this casual appeal to observational evidence.

We can get some idea of the popularity of sundials in the first century A.D. from the large number found at Pompeii—nearly three dozen, found in public squares and private gardens. Of course, Pompeii was an expensive resort town, and far from typical. Still, these objects must have been quite common in cities of any size.

We moderns are used to seeing inscriptions on sundials, perhaps reminding us of the associations of the fleeting shadow, perhaps asking us to meditate on our cosmic connections. One of my personal favorites occurs on an eighteenth-century dial in Nyon, Switzerland: "Qui trop me regarde perd son temps." ("Who looks at me too much wastes his time"). Inscriptions of this sort do not occur on ancient Greek and Roman sundials. Indeed, most ancient dials have no inscriptions at all. And for those that do, the most common is the name of the donor, or, more rarely, the name of the maker of the dial. However, literary epigrams *about* sundials do occur. One of the jocular insult epigrams of the *Palatine Anthology* compares the nose of the object of humor to the gnomon of a sundial:

> If you put your nose to the sun and open your mouth,
> you will show the hours to all who pass by.
> (*Greek Anthology*, xi, 418. See Paton, 1969, for the Greek text).

This epigram is attributed to the Emperor Trajan, though one need not take the attribution too seriously.

A number of epigrams in this collection involve riddles or arithmetical problems. One of the latter, concerning the time of day, is made sharper by purportedly addressing itself to a maker of sundials:

> Diodorus, great glory of gnomonicists, tell me the hour since when the golden wheels of the Sun leapt up from the east to the pole. Four times three-fifths of the distance he has traversed remain until he sinks to the western sea (*Greek Anthology*, xiv, 139. Translation adapted from Paton, 1969, volume 5, p. 101).

(The answer is: 3 9/17 hours have passed since sunrise, 8 8/17 remain till sunset. For those who wish to solve the problem, remember that the time is expressed in seasonal hours.)

We are used to metaphors of mortality expressed in terms of time-keeping devices: the sands of time, the final hour. Images of sundials were occasionally used in this way in Roman sculpture. For example, there is a sarcophagus in the Louvre (MA 355), from the early third century A.D., which is decorated with a relief of the cycle of Prometheus, including the creation and the destiny of Man. Near the figure of Death, and behind the three Fates, Atropos, Clotho and Lachesis, is a sundial on a column. Other sarcophagi in the Louvre with images of sundials are MA 284 and MA 1341.

In Rome, a sundial of monumental size served to make a political statement. In 10 B.C., Augustus had constructed on the Field of Mars a horizontal, plane sundial with a gnomon 100 Roman feet (30 meters) high (for details see Buchner, 1982, and for a short account, Claridge, 1998: 190-192). The gnomon was an ancient obelisk of pink granite that had been taken from Heliopolis in Egypt (Strabo, *Geography*, xvii, 1.26). The gnomon still survives, and stands now in the Piazzi di Montecitorio, some 200 meters southeast of its original location. In the inscription on the side of the gnomon's base, Augustus dedicated the dial to the Sun, in commemoration of his own annexation of Egypt some twenty years before. So here a monumental gnomon and sundial serve imperial aims, not only by celebrating the military strength of the Emperor, but also by affirming his association with the Sun god. Although the metal sphere that now tops the obelisk is not original, we know that the gnomon originally did indeed carry just such a sphere, as it is mentioned by Pliny (*Natural History*, xxxvi, 70-73). And it is also represented on a relief sculpture of the apotheosis of Antoninus Pius (now in the Vatican Museums), which shows a personification of the Field of Mars holding the gnomon of Augustus, complete with sphere at the top (for photographs of this, see Claridge, 1998: 194; Gundel, 1992: 78).

The dial face must have been similar to that of a standard horizontal, plane dial, such as that in Figure 5. Pliny tells us that it was designed by a mathematician named Novius Facundus, who is otherwise unknown, but who must have been an excellent gnomonicist. According to Pliny, bronze markers in the pavement allowed one to measure the length of the noon shadow day by day. Remarkably, a short section of the stone and bronze meridian of Augustus' dial was discovered in 1979/1980 and answers precisely to this description. The meridian is divided into signs of the zodiac, labeled with their names in Greek, and the signs are subdivided into individual degrees (at least for the portions not too near the tropics). It is interesting that a dial commissioned for public display at Rome should be engraved in Greek. This no doubt reflects the status of Greek as the recognizeed language of science, and particularly of astronomy.

Augustus' monumental dial also incorporated some features of a parapegema.[4] At intervals along the meridian were notices of important events in the cycle of the seasons, for example, the beginning of summer, or the cessation of the etesian winds. The etesian winds are annually-recurring (hence their Greek name) north winds that blow in the Mediterranean in summer, giving some relief from the heat. They were commonly held to begin blowing at about the morning rising of the Dog Star, and to last for two months. The great dial of Augustus has them stopping shortly after the Sun enters Virgo, which agrees with other ancient parapegmata.

Pliny tells us that by his day (ca. A.D. 70), readings taken from the sundial (presumably of seasonal clues, such as the Sun's place in the zodiac, which could easily be checked against a calendar) had been out of agreement with the facts for about thirty years. He conjectures that this might have been caused by a shift in the position of the gnomon (despite its very deep foundations), by a change in the course of the Sun, or perhaps by a small shift of the Earth itself from its central position. For the latter, says Pliny, there is also some evidence from other locations.

6. CONCLUDING REMARKS

In this paper I have tried to show how intimately gnomonics was connected with other aspects of life in Greek and Roman antiquity. Gnomonics was a specialized genre of applied mathematics, with its own literature, as well as a trade practiced by skilled masons. It had vital links to the theory of the celestial sphere, as well to *sphairopoiïa* and other mechanic arts. Sundials were important enough as architectural ornaments that Vitruvius felt it necessary to treat them in his *Ten Books on Architecture*. Sundials provided a way of showing off a gnomonicist's skill, or of demonstrating a patron's wealth and sophistication, of making a bittersweet observation on human mortality, of flattering a ruler, or of asserting the grandest of imperial ambitions. All that—and they told time, too. The MarsDial, which has much more to say about human aspirations than about the time of day on Mars, stands squarely in a vital tradition.

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8. NOTES

1. See Pliny's (*Natural History*, vii, 191-209) fabulous list of inventors, including the inventors of houses, ships and cities. For an astronomical example, see Eudemus' list of astronomical discoveries, as reported by Theon of Smyrna (*Mathematical Knowledge Useful for Reading Plato*, iii, 40; Dupuis, 1892: 320-321).
2. Gnomonics showed a rich development in the Arabic Middle Ages, including its adaptation to the needs of Islam by incorporating curves on the dial to indicate prayer times. These developments are beyond the scope of this paper, but for a fascinating introduction see Savoie (2004), which includes references to a substantial literature on Arabic/Islamic sundials.
3. Several ancient dials call attention to the variation in the length of the day throughout the year, by comparing the length of the winter solstitial day to the other days of the year. These are Gibbs Nos. 1044, 1068, 3046 and 4001. For a discussion of the latter see Evans (1998: 130-131).
4. For an introduction to parapegmata, see Evans (1998: 199-204) and Taub (2003: 20-37). For a catalogue of all known examples see Lehoux's (2000) Ph. D. dissertation.

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