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76. See Ibid.
77. John Evelyn, *Elysium Britannicum, or The Royal Gardens* (ca. 1660), ed. John E. Ingram (Philadelphia: The University of Pennsylvania Press, 2001), 231, 242, 191.
78. Evelyn, *Elysium Britannicum*,184, 439.
79. Anne-Louise d'Orléans, duchesse de Montpensier, *Mémoires de Mlle. de Montpensier*, ed. Bernard Quilliet (Paris: Mercure de France, 2005), Chapter XXIII (July–September, 1656). The owner of the estate, whom the writer identifies as "Esselin," was Louis Cauchon d'Hesselin, who served as Maître de la chambre aux deniers de la maison du roi. Madame de Lixein was Henriette de Lorraine, daughter of François de Lorraine, who had married the Prince of Lixen.
80. Robert Darnton, *The Great Cat Massacre and Other Episodes in French Cultural History* (New York: Vintage, 1985), 78.
81. Henri Bergson, *Laughter: An Essay on the Meaning of the Comic*, tr. Cloudesley Brereton and Fred Rothwell (Whitefish: Kessinger Publishing, 2004 [first published in French as *Le rire: essai sur la signficance du comique* (Paris: Editions Alcan, 1900)]), 16, 81. For Freud's use of Bergson's theory of humor in his own very different account, see Sigmund Freud, *Jokes and Their Relation to the Unconscious*, tr. James Strachey (New York: W.W. Norton, 1963 [first published in German as *Der Witz und Seine Beziehung zum Unbewussten* (Leibzig and Vienna: Deuticke, 1905)]), Chapter 7, especially 259–260.
82. For an anthology of recent treatments of this subject, see Jan M. Bremmer and Herman Roodenburg, eds., *A Cultural History of Humour: From Antiquity to the Present Day* (Cambridge: Polity Press, 1997). Peter Burke, in Chapter 5 of the volume, "Frontiers of the Comic in Early Modern Italy, c. 1350–1750," mentions Renaissance palace waterworks in passing, p. 65. The history of humor is an integral part of the discussion in Norbert Elias's classic work, *The Civilizing Process: Sociogenetic and Psychogenetic Investigations* (London: Blackwell, 1994 [first published in German as *Über den Prozess der Zivilisation* (Basel: Haus zum Falken, 1939)]).

12

Cosmography and the Meaning of Sundials

Jim Bennett

The sundial conundrum

In the history of the use of geometry to regulate our engagement with the motions we observe in the heavens, we find in dialing the widest gap between the commitment and enthusiasm of historical practitioners, and the attentions of historians. Astrology now has a scholarly community to recover and communicate its theories, methods, influence, and social and cultural significance. Dialing—despite an enormous following in its Renaissance and early modern heyday, the penetration of its practice to almost all levels of society, and the complexity, subtlety, and originality of its development by leading geometrical astronomers—now languishes beyond the concerns of nearly all historians, its memory sustained by enthusiasts for instruments and by practitioners more engaged with the exercise of horological geometry than with its history. A recent exception has been John Heilbron's book *The Sun in the Church*, telling the story of some of the grandest of all sundials, where the image of the sun thrown by an aperture high in a vault or a facade of a great church marks and measures the annual solar cycle by a meridian line set into the floor.[1]

One reason for the more general neglect is surely a misapprehension of the role of dialing in the Renaissance and an impoverished appreciation of its purpose. In short, we too readily restrict its function to telling the time. Where sundials are functional today, from the monumental to the recreational, they do little more than simply tell the time and, even then, this is not a method of time-telling that anyone would rely on. We are touchingly surprised when a sundial we come across might work at all, forgetting for the moment that it represents the source and regulation of all our time-telling. The danger for historians is to project that impoverished functionality back into the sixteenth century, when dialing was pursued by the leading geometrical astronomers. The design at the center of this article, for example, was the work of no less an astronomer than Johannes Regiomontanus.

The Regiomontanus dial appeared initially in the astronomer's *Kalendarium*, first published in Venice in 1474.[2] Figure 12.1 is an expanded and more detailed representation, more typical of surviving instruments from the sixteenth century, taken from Oronce Finé's *De Solaribus Horologiis et Quadrantibus* of 1560. What assumptions can a modern author make about his historian readers, even if they are well-informed on sixteenth-century astronomy? How might they engage with an image such as this and what might it mean to them? If it concerned planetary theory, for example, comprising a deferent circle and an epicycle, he could be fairly confident in taking as understood an appreciation of its basic purpose and functionality. Here he cannot have that confidence,

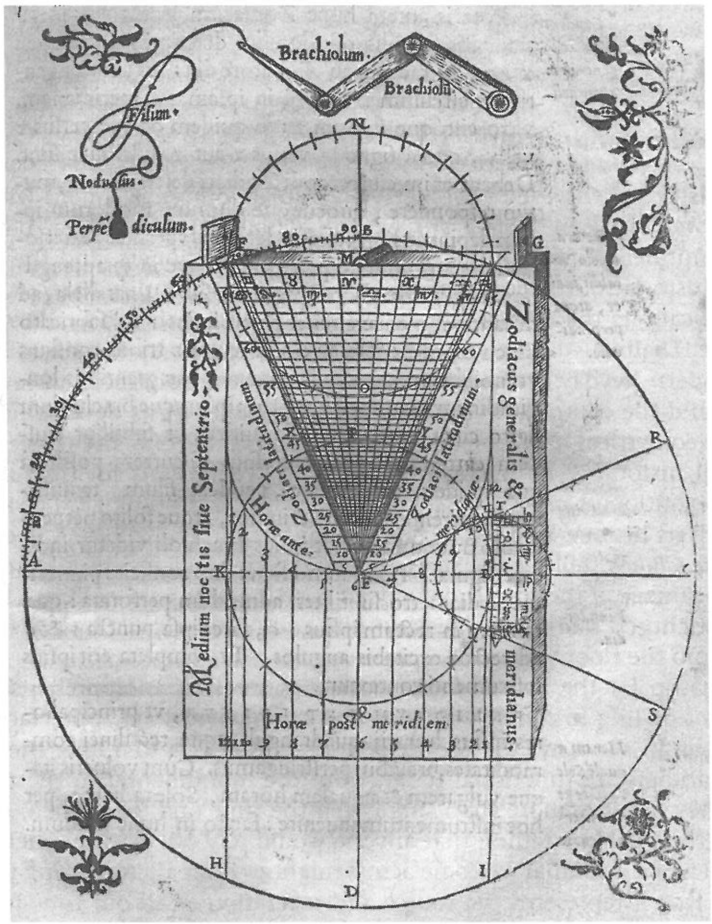

Figure 12.1 The Regiomontanus dial from Oronce Finé, *De Solaribus Horologiis et Quadrantibus* (Paris, 1560). All the figures are © Museum of the History of Science, Oxford.

even though an image such as figure 12.1 is a much more common occurrence in the astronomical geometry of the sixteenth century than is a theoric of planetary motion.

Telling the time "here and now" is of course a feature of the Regiomontanus dial, even if we may agree eventually that it is only part of the story. Time-telling is achieved by means of the altitude of the sun, but it might be misleading to say that the altitude is "measured," since it is not known at the end of the operation. What becomes known is the current local time, derived by the instrument from the solar altitude. There are two other variables to take account of in this operation: the solar altitude depending on the time of year and the latitude of the observer, as well as the time of day. Date and latitude are adjusted for by setting the point of suspension of a plumb-line (a weighted thread suspended from the tip of an articulated arm) to the intersection of the appropriate values for these variables on the triangular grid on the upper part of the dial, and then extending the thread from this point across the date (zodiac/solar declination) scale on one side of the dial (to the right in figure 12.1). A bead on the thread is slid into place at its intersection with the appropriate zodiacal position of the sun. Then, with the instrument held vertically, when the sights at the top are trained on the sun and the thread hangs freely, the bead will indicate the time on the vertical hour lines on the lower part of the dial. The central line indicates 6 o'clock, while the extreme lines to the left and right are for midnight and midday respectively. If the reader is wondering why a sundial should have a line indicating midnight, a doubt has been sown that the instrument is not simply for telling the time "here and now."

Sundials as mathematical instruments

We do not yet have the general history of Renaissance and early modern sundials that would extend their story beyond its current location in a geometrical and technical discourse and demonstrate its significance for other themes in social, intellectual, and cultural history. Dials could be objects of prestige and patronage, symbols of learning, or of devotion and piety. A monumental dial could be a project worthy of a prince. Utilizing the different edges and planes of a crucifix for casting and receiving shadows might create an object of devotion, even in some cases a reliquary to wear. Sundials were natural candidates for *memento mori*. Yet there was a range of products from instrument workshops that catered for a wide diversity of society.[3] In *As You Like It*, Shakespeare has Touchstone consult a dial he carries in his bag, an event undeserving of the moral soliloquy the "fool" then elaborates from this everyday gesture:

> And then he drew a dial from his poke,
> And looking on it, with lack–lustre eye,
> Says, very wisely, "It is ten o'clock."[4]

If the bawdy reading sometimes offered was intended, so much the more noteworthy that the theater audience was assumed to be familiar with portable sundials.

The notable development of dialing in the sixteenth century was one instance of what might be called a craft tradition in astronomical practice that was characteristic of the period. The work of a practitioner such as Gerard Mercator demonstrates an integration of learning and skill, as he combined the work of engraver, cartographer, cosmographer, printer, and instrument-maker. Other examples, among many, would be Johann Schöner, Georg Hartmann, Peter Apian, and Gemma Frisius. Innovative astronomy and cartography were disseminated through objects made by craftsmen in the leading workshops and print-shops. Some of these objects were themselves important inventions, such as the printed atlas or the printed globe.

If a rich history of sundials, a further instance of astronomical craft, is yet to be written, in recent years we have learnt much about the general class of mathematical instruments, to which they belong, and have taken greater care over how we characterize such instruments. In particular we are careful not to equate their functionality with that of the later class of *scientific* instruments. Instruments from the sixteenth century—"mathematical" instruments, as they were known—scarcely ever espoused pretensions to discover truths about the natural world. They were for solving problems susceptible to mathematical treatment, such as finding the time, a position at sea, or the range of an artillery target; or laying out a fortification or drawing a map.

This does not mean that they might not be technically sophisticated, far from it. Although they scarcely engaged with causal explanations in the manner of natural philosophy, their operations were grounded in the mathematical *science* of geometry and their output—designers and commentators insisted—was correspondingly reliable. Our next section follows the sixteenth-century geometrical discourse of the Regiomontanus dial, revealing something of the nature of this mathematical practice by working through a little of it, and revealing its constructive or crafted character.

The sixteenth-century discourse of the Regiomontanus dial: An exercise in practical geometry

If a sundial whose operation extends to midnight sits outside our usual characterization of such an object, where might we place the Regiomontanus dial in the broader context of sixteenth-century learning? One source of guidance would be to follow carefully the way it is presented in the texts of the period, when there is a vogue for printed descriptions of the construction and use of mathematical instruments. To this end we shall take the early account of Sebastian Münster, first published in his *Compositio Horologiorum* of 1531,[5] where, in keeping with the convention adopted in these texts, the reader is taken through the construction of the instrument as a practical geometrical exercise. This will allow us to imitate John Heilbron's expository technique in his *Geometry Civilized*,[6] where engaging with geometry becomes a route to historical insight, by taking the reader into the mathematical literacy of a time and a culture.

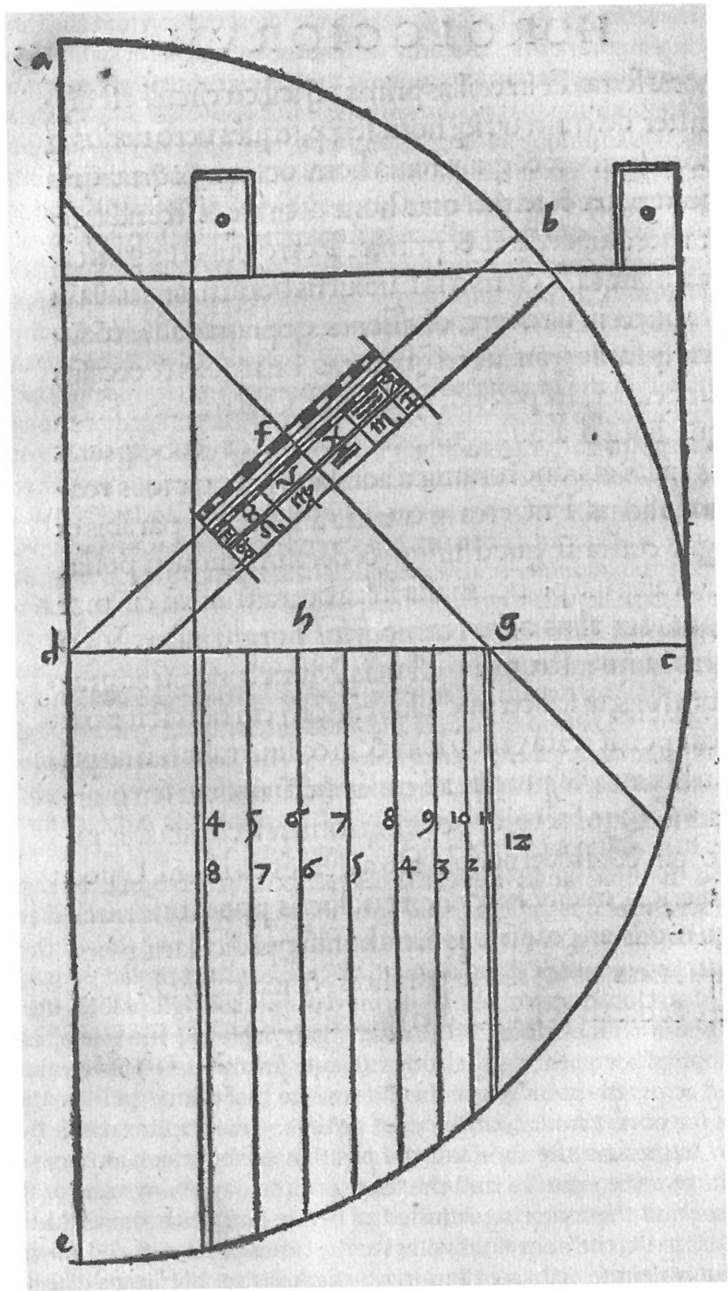

Figure 12.2 The construction of the rectilinear altitude dial sometimes called the "Capuchin dial," from Sebastian Münster, *Compositio Horologiorum* (Basel, 1531).

Here, however, we shall stick closely to the presentation and the limitations of the contemporary text, the only difference being that it will be helpful to introduce a simpler dial before moving to the instrument of Regiomontanus. This simpler altitude dial is not universal, but confined to a single latitude. The didactic technique of beginning with the simpler instrument can be found in modern treatments of the Regiomontanus dial but was not adopted by either Münster or Finé. Since Münster does deal with this dial at a later stage in his treatise, we can allow his account to present it also.[7]

Münster begins with instructions to draw a semicircle on a vertical diameter (see figure 12.2), divide it into two quadrants, and divide the upper quadrant arc into 90 degrees. The reader is then to mark off from the top of this quadrant the latitude where the dial is to be used, draw in the radius at this latitude, and on the line of the radius construct a zodiacal scale. The normal to this radius at its center f intersects the lower radial edge of the quadrant (dc) at the point g. Centered at g, arcs of 23 degrees 30 minutes are set out on either side of gf, the terminal radii being said to represent the tropics. Angles are then given for the other boundaries between the zodiacal signs, so that the reader can construct the complete zodiacal scale. A line from f parallel to the diameter of the semicircle will be the line for both the hours of 6 (morning and evening) and intersects dc at the point h. The reader is told to construct a semicircle below h with the radius hg and divide it into 12 equal parts. Parallels to the hour line for 6, drawn from the divisions on the semicircle, moving toward g, will be the lines for the pairs of hours 7 and 5, 8 and 4, 9 and 3, 10 and 2, 11 and 1, and ending with 12 midday at g. At this point Münster suggests that subdivisions of the hours may be added, so as to be useful when finding the length of day and times of sunrise and sunset through the year—an indication that the instrument is not just for finding the time here and now.

To find the time, however, two vanes, pierced for receiving the rays of the sun, are set above the zodiacal scale on a line at right angles to the diameter of the semicircle, and a slot is cut in the zodiacal scale on the line of the radius. In this slot moves a cursor and from it hangs a weighted thread with a pearl or some less precious index that can be moved, friction-tight, along the thread. When used for time-telling, as Münster then explains, the cursor is moved to the appropriate point on the zodiacal scale for the time of year, the thread stretched across the point g, and the index set to that point (g will be the bead's position for noon throughout the year). With the dial held vertical, the sights are then trained on the sun, and the position of the index among the hour lines will give the time. To find the length of the day at any time of the year, the cursor and the index are adjusted as before and, with the thread set perpendicular to dc, the hour lines will give the times of sunrise and sunset, since this is equivalent to sighting the sun on the horizon. Münster's dial has hour lines to the left of the line for 6, symmetrical to those on the right, up to 4 in the morning and 8 in the evening, the maximum length of day in the latitude for which the dial is constructed and coinciding with the perpendicular from the cursor's position at the summer solstice.

Münster offers his readers nothing further by way of geometrical proof or even plausible explanation for why this construction may be relied upon to find the time or yield the length of day throughout the year. If we consider the situation at the equinoxes, f may be regarded as the center of the celestial sphere and the path of the sun for the day would lie in the plane containing fg at right angles to the page. The circumference of the sphere is traced by the arc through g centered at f, that is, the path of the bead of the sundial. The hour lines as drawn are orthographic projections of the lines of equal altitude for the whole-hour positions of the sun, that is at 15-degree intervals in the circle, hour 6 being the horizon (altitude zero) and 12 being the meridian altitude, which at the equinox is the complement of the latitude. For other dates in the year the sun will be on a different circle on the celestial sphere and the orthographic projection of the lines of equal altitude will be different, which would be incompatible with a useful sundial. This dial accommodates that by changing the radius of the arc traced by the bead, while moving the point of suspension also accommodates the changing relationship between the daily path of the sun and the horizon. (The geometry is correct though no proof of this is given.[8])

Despite the simplicity of this dial in its construction, it is a relatively sophisticated piece of geometry, especially in the way the same pattern of lines serves for different positions of the projection of the daily solar motion on the celestial sphere. It works in only a single latitude, and it might be thought that adding different declination lines for different latitudes would rapidly make the instrument complicated and unmanageable. But Peter Apian offers solutions in quadrant designs included in his *Instrument Buch* of 1533.[9] In one quadrant there are zodiacal scales for every 2 degrees of latitude from 30 to 60 degrees and a scale along the meridian or 12 o'clock line for use in adjusting the bead for the corresponding latitude. The result is more an instrument for calculation than immediate time-telling. Among the multifunctional applications of a second instrument (figure 12.3) is a similar dial where zodiacal scales are provided for latitudes from the equator to the arctic circle, the scale for the equator being set vertical, in line with the hour line for 6 and indicating no variation in the times of sunrise and sunset throughout the year. (Ignore the curved lines for this purpose: the relevant hour lines are the straight, vertical ones.) We shall return to the clear geographical—or, more properly, cosmographical—meaning of such an instrument.

In fact a very satisfactory solution to extending the latitude range of the rectilinear altitude dial already existed in the Regiomontanus dial. We shall again follow the instructions given by Sebastian Münster, who provides the reader with two woodcuts—one is for following the details of the construction (figure 12.4), whereas the other is a finished instrument.[10] Münster begins with instructions to draw a circle and to divide one of its quadrants into degrees, beginning with 0 at the horizontal point a. The reader is then told to mark off the maximum declination of the sun, 23 degrees 30 minutes, on both sides of the 90-degree mark, b, giving h and f, and on either side of the point d, diametrically opposite to b, giving i and g. Münster says that the

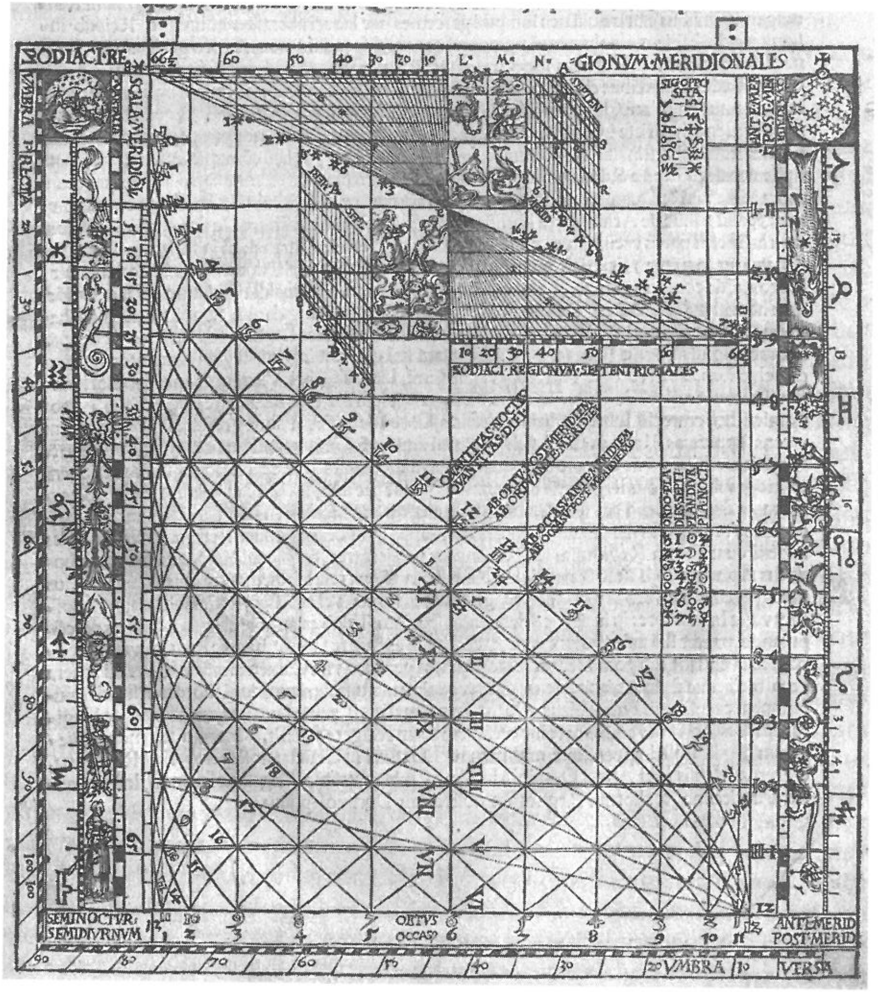

Figure 12.3 An horary quadrant from Peter Apian, *Instrument Buch* (Ingolstadt, 1533).

lines hi and fg represent 12 midnight and midday, and that the other hour lines will fall in the space between.

He then describes the construction of the triangular grid in the upper part of this space, beginning by drawing ef and eh to represent the tropics of Capricorn and Cancer. Dividing a circle constructed on hf as diameter into 12 equal parts gives the zodiacal divisions of the sun's annual motion, which are projected orthographically on to hf and joined by lines drawn to e. The latitude component of the grid is added by finding the intersections between the lines from the center e to the required latitudes and the line fm, and from these points of intersection lines are drawn, numbered appropriately,

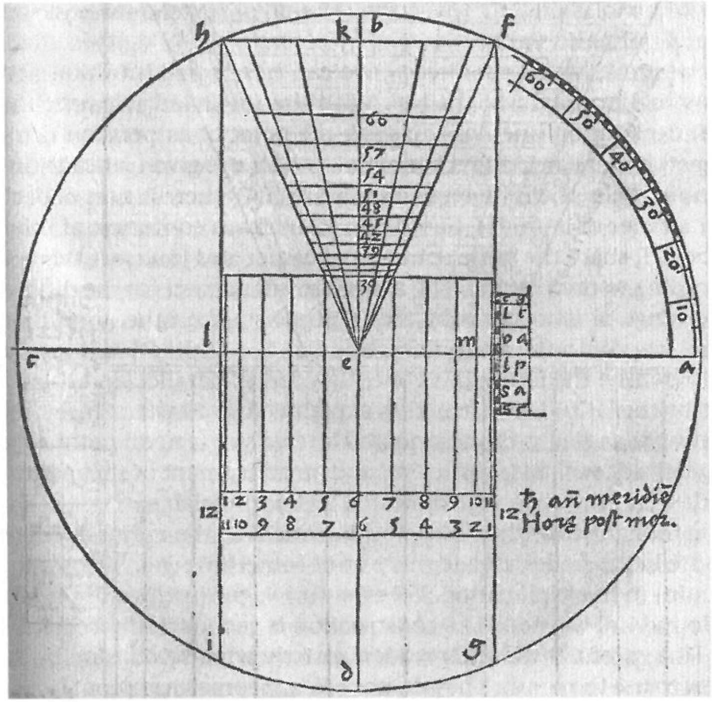

Figure 12.4 The construction of the Regiomontanus dial, from Sebastian Münster, *Compositio Horologiorum* (Basel, 1531).

parallel to ca and contained by the boundaries of the triangle, representing the tropics.

The reader is then instructed in drawing the hour lines by constructing a circle on lm and dividing it into 24 equal parts; the lines through these divisions parallel to bd each serve for morning and afternoon hours: 7 and 5, 8 and 4, 9 and 3, 10 and 2, and 11 and 1. Subdivisions of the hours are also possible. The reader is then told to transfer the zodiacal scale for the 45-degree latitude line to the line fg, centered at m, where the scale can be subdivided and marked with the signs of the zodiac.

Münster's instrument is completed by an arm that is adjustable over the triangular grid, so that a weighted thread with an adjustable bead can hang freely from any point in the grid, and by a pair of sights set above the transverse line for the most northerly latitude. For direct time-telling by the sun, as we have already seen, the arm is set to the appropriate intersection of latitude and zodiacal sign on the triangular grid, the thread stretched across the appropriate point of the zodiacal scale on the side of the hour lines, and the bead brought to this intersection. With the dial held vertical, the sights are trained on the sun, and the position of the freely hanging bead among the hour lines will indicate the time. However, as Münster points out, as the full cycle of 24 hours is present, this curious "sundial" extends at least some of its functionality to midnight.

From what we have seen already, we can have some intuition about why this construction might fit the bill. With the single-latitude rectilinear dial, the solar declination line, for adjusting the point of suspension through the year, is perpendicular to the equinoctial line for the given latitude. In each of the Apianus dials (one is illustrated in figure 12.3) there is a set of declination lines for a range of latitudes, but so as not to have a confusion of intersecting lines, they all share the same equinoctial center and intersect there, fanning out according to the latitude. The necessary adjustment for the different radii over the range of latitudes is by that latitude scale on the noon line, where the bead is set. With the Regiomontanus dial, the declination lines are set out quite differently: the fanning is gone; they are all parallel; and their position is found by the latitude construction explained by Münster. Since they are no longer at right angles to the equinoctial lines, a single noon point adjustment for each latitude will be insufficient, and an adjustment of the radius is given by a scale that introduces an additional zodiacal variable.

A little thought confirms that the adjustment to the radius operates in the right sense but a modern reader may want something much closer to a proof at this point in the explanation. Yet even this vague justification is more than can be found in Münster. (The construction is geometrically correct. [11]) Both he and Finé carefully tell their readers exactly what to do, step by step, and then how to use the result. They do not offer a geometrical proof for establishing the instrument's legitimacy. Typical of this genre of mathematics, at least in its published presence, legitimacy comes from the use of a set of geometrical techniques accepted within mathematical practice.

The Regiomontanus dial as an instrument of cosmography

What qualities are presented by this dial? Why take these steps to arrive at just the properties and characteristics it offers, with its rectilinear arrangement of hour lines and its distribution of parallel lines arranged by ascending latitude, each with an appropriate scale of solar declination? Its functionality can be viewed in the context of Münster's wider reputation, which lies, of course, in cosmography. Finé too, though a polymath in the geometrical arts and sciences, is mainly remembered as a cosmographer, although horology and cosmography form a ubiquitous conjunction in the sixteenth century.[12]

The discipline of cosmography deals with the presentation of the whole cosmos—the heavens *and* the earth—and in particular the relationship between them. As John Dee explained succinctly in his "Mathematicall Praeface" to Henry Billingsley's English translation of Euclid of 1570, "Cosmographie, is the whole and perfect description of the heauenly, and also elementall parte of the world, and their homologall application, and mutuall collation necessarie."[13] Cosmographical astronomy emphasized that the imaginary circles according to which we organize the spatial account of our stationary earth—equator, tropics, and lines of latitude—are equivalent to and originate

in the corresponding circles in the movement of the heavens. Münster's book on sundials begins, in the way a contemporary cosmography might begin, with the celestial sphere and the motion of the sun. Cosmography has to deal with the starry heavens and their daily motion about the pole, their appearance from different parts of the earth marking out geographical location. It does not move on from there to tackle the motions of all the planets: Ptolemy's *Geographia* (or *Cosmographia*, to use the more common title from the sixteenth century) is restricted to the motions of the stars and the sun, the other planets being the business of his *Almagest*.

Dee offers a material and instrumental commentary on the way the circles of the heavens are applied to the earth, by referring to the contemporary practice of drawing them on a terrestrial globe. Although there were, as yet, no English globes, he was familiar with this practice from his association with Gemma Frisius and Gerard Mercator. The art of cosmography, Dee explains, "matcheth Heauen, and the Earth, in one frame, and aptly applieth parts Correspōdent: So, as, the Heauenly Globe, may (in practise) be duely described vpon the Geographicall, and Hydrographicall Globe." The word "describe" is used here in its original, literal sense, as it still is in geometry, where a circle might be "described." Dee's "frame" also has a literal sense: he adds to his explanation of the circles their accommodation in a stand with a horizon ring: "by an Horizon annexed, and reuolution of the earthly Globe (as the Heauen, is, by the Primouant, carried about in 24.æquall Houres) to learne the Risinges and Settinges of Sterres." Here Dee points very particularly to the curiosity of this instrument, where the heavenly circles are described on the terrestrial globe to create what he calls a "cosmographical globe": the globe of the earth is given a rotation on the poles of the heaven for the convenience of cosmography. "By the Reuolution, also, or mouing of the Globe Cosmographicall, the Rising and Setting of the Sonne: the Lengthes, of dayes and nightes: the Houres and times (both night and day) are knowne." This revolution does not have a Copernican meaning; it is "artificial," the globe being an instrument of the art of cosmography.

In the context of this discipline, time is the most immediate link between the heavens and the earth, and the astronomical component of cosmography therefore incorporates the motion of the sun, adding the ecliptic circle to the celestial equator and the tropics, and "describing" it on the cosmographical globe. Ptolemy refers to the successive parallels of latitude in terms of the lengths of the longest day in those places on the earth.

Münster and Finé are far from being unusual in the period for combining cosmographical work with a concern for dialing. Examples range from small portable dials to cathedrals with meridian lines, such as the meridian in Florence by the cosmographer Paolo dal Pozzo Toscanelli.[14] Other prominent practitioners were Peter Apian, Johannes Stoeffler, Gemma Frisius, Gerard Mercator, Erlard Etzlaub, Johannes Werner, and Johannes Stabius. Working in Florence on the great cosmographical project of Cosimo I de' Medici—now surviving as the geographical room in the Palazzo Vecchio—were Miniato Pitti, Egnatio Danti, and Stefano Buonsignori.[15] After his enforced move to

Bologna, Danti built a meridian line there, while a Bolognese example of the cosmographer and dialist would be Giovanni Antonio Magini. The northern dominance of cosmography toward the end of the sixteenth century brings in Willem Janszoon Blaeu and Michiel Coignet.

The need or desire to find the time here and now is a hopelessly inadequate motive for the development of sundials we see in the sixteenth century, evident in both published treatises and surviving instruments. A solution to this historical conundrum is to take the dials, or at least the more ambitious designs, out of simple time-telling, to see them instead as instruments of contemporary cosmography, and to link the enthusiasm for sundials—universal dials in particular—with the contemporary rise of cosmography.

An instrument like the Regiomontanus dial, or "general horological quadrant" as Münster calls it, is not adequately characterized in the way we think of our simple and impoverished sundials of today, so that we are obliged to imagine a traveler carrying his dial to different parts of the world where he uses it to tell the time. That is only part of the intended or pretended functionality. A different class of dial from the altitude quadrant, the universal equinoctial dial, also has a clear cosmographical context—being adjustable to latitude by bringing its hour circle parallel to the equator and its gnomon in line with the pole. This adjustment is surely something we might more easily think of as a cosmographical gesture for the generality of owners and users than as a resetting for an unfamiliar location, according to the extensive travels of the user. The tables of the latitudes of places, found on many dials with latitude adjustment, might be seen as an aide-memoire for the travelling user, but they are also reminiscent of the latitude tables in Ptolemy's *Cosmographia*.

If we look at the Regiomontanus dial in this context, we can begin to see its advantages and to understand the investment of geometrical work involved in its design. Think of it more as a kind of map than as a dial, but at the same time think of a map more as a geometrical "theoric" than a picture or a bird's eye image of the earth. A theoric was an encapsulation of information, secured by a systematic technique (usually a geometrical one), in a device that might be an instrument but could also be a diagram or a construction. Results could be obtained from the theoric that were not entered in its construction and that were extracted by applying the proper protocols by the knowing user. As the vehicle for an operative technique rather than a causal explanation, the theoric belongs in the mathematical arts and sciences rather than in natural philosophy. The example most familiar to historians is the theoric of planetary motion, but mathematical practice has many other examples in different disciplines and a map drawn to scale is such a device. At the level of the world map, the theoric can take a variety of forms, shaped by different geometrical projections, and these varieties can coexist to be deployed according to their suitability for different purposes. They have different properties and advantages. So it is with the instruments we call sundials.

The Regiomontanus dial sets out very effectively the relationship between the seasonal variation in the length of the day and the latitude, presented

systematically by increasing latitude and the correspondingly lengthening declination scales, indicating the growing discrepancy between summer and winter days. We might look at this as a kind of map, with information set out in a projection, but here the information incorporates the variable of time in relation to latitude and date. Looking at figure 12.1, you can see that at the equinox the sun rises at 6 everywhere in the world; that this is the case at the equator throughout the year, the declination "scale" being reduced to a point for latitude zero; that at the equator the sun is at the zenith at noon at the equinoxes; that there is a range of latitudes where the sun can ever reach the zenith; and so on. And of course by positioning the suspension point appropriately, you can find the times of sunrise and sunset and the length of the day for any date at any latitude (or rather, up to 65 degrees north in this example). So a great many cosmographical operations can be performed, in addition—if there is a pair of sights—to finding the time here and now.

The Regiomontanus dial is not the only "sundial" whose meaning is enhanced and whose apparent incongruity is resolved by closer attention to its disciplinary location. A form of what today would be called a universal altitude dial is described by Finé under the name "horologium generale."[16] Though not in Münster's treatise, it became familiar in the sixteenth century by its appearance in the many editions of Apian's *Cosmographia* as a working paper *volvelle* with rotating parts and index threads. Apian tells his readers how to use the paper instrument on the page of their book to solve such problems as finding the latitude from the altitude of the sun (knowing the date); the time from the sun knowing the latitude and date; the altitude of the sun anywhere knowing the time, date, and latitude; the times of sunrise and sunset anywhere; the length of the day; and so on. As the instrument is intended to be used, time is one parameter in the complex of interdependent variables that belong to the business of cosmography. Time is integral to its functionality, but once again this is not an instrument just for finding the time here and now, in the manner of a sundial as generally understood.

An instrument in the collection at the Museum of the History of Science has on one face a brass version of the *horologium generale* and on the other a second *volvelle* from Apian's *Cosmographia*, his "speculum cosmographicum," translated from paper into brass.[17] Here the planispheric projection of a normal astrolabe is applied to the earth rather than the heavens, so the only plate is a terrestrial planisphere extending to the Tropic of Capricorn. Above this rotates a rete comprising only a zodiacal band with eight stars within (i.e. to the north of) the ecliptic. Above this in turn, pivoted at the center (i.e. the pole), is an index arm extending to a time scale beyond the planisphere. The user who had access to Apian, as any user surely did, would have known how to trace the daily and annual cycles of the sun in relation to the earth, how to find where the sun is overhead for the user's time for any date, the time differences between geographical locations, and so on. Although this instrument is generally, and perfectly reasonably, referred to as a "geographical astrolabe," the combination of the *speculum cosmographicum* and the *horologium generale* makes it a versatile instrument of cosmography. It was made by

Gillis Coignet of Antwerp, whose son Michiel continued the cosmographical tradition in books as well as in instruments. An instrument by Michiel Coignet in the Oxford collection combines the *horologium generale* with the nocturnal, which was also described by Apian in his *Cosmographia*.[18]

If we are unwilling to call the great meridian instruments built into Renaissance cathedrals mere "sundials," then that reluctance should apply to many small, portable instruments as well. Or, we could instead avoid the perils of projecting the impoverished functionality of modern dials back on to the sixteenth century. Either way, we might encourage historians to pay more attention to a geometrical discipline that its many practitioners found engaging, satisfying, and meaningful.

Notes

1. J. L. Heilbron, *The Sun in the Church: Cathedrals as Solar Observatories* (Cambridge, Mass. and London: Harvard University Press, 1999).
2. I have used the 1476 edition of Johannes Regiomontanus, *Aureun hic Liber est: Non est Preciosior ulla Gemma Kalendario* (Venice, 1476).
3. See, for example, the range of ivory diptych dials, Penelope Gouk, *The Ivory Sundials of Nuremberg 1500–1700* (Cambridge: Whipple Museum of the History of Science, 1988).
4. William Shakespeare, *As You Like It*, 2nd series, ed. Agnes Latham (London: Arden Shakespeare, 1975), 2.7.20–2.7.23.
5. Sebastian Münster, *Compositio Horologiorum* (Basel: Heinrich Petri, 1531), 25–31; see also Sebastian Münster, *Horologiographia* (Basel: Heinrich Petri, 1533), 35–43.
6. J. L. Heilbron, *Geometry Civilized: History, Culture and Technique* (Oxford: Oxford University Press, 1998).
7. Münster, *Compositio*, 151–154; Münster, *Horologiographia*, 250–254.
8. F. W. Cousins, *Sundials: A Simplified Approach by Means of the Equatorial Dial* (London: John Baker, 1969), 168–174.
9. Peter Apian, *Instrument Buch durch Petrum Apianum erst von new beschriben* (Ingolstadt, 1533).
10. Münster, *Compositio*, 29–30; Münster, *Horologiographia*, 40–41.
11. For a modern proof, see A. W. Fuller, "Universal Rectilinear Dials," *The Mathematical Gazette* 41 (1957): 9–24.
12. I have offered a more general account of the connection between dialing and cosmography in "Sundials and the Rise and Decline of Cosmography in the Long Sixteenth Century," *Bulletin of the Scientific Instrument Society*, no. 101 (2009): 4–9.
13. John Dee, "Mathematicall Praeface," in Euclid, *The Elements of Geometrie*, tr. H. Billingsley (London, 1570), sig. b. iii.
14. Heilbron, *The Sun in the Church*, 70–71.
15. Jim Bennett, "Cosimo's Cosmography: The Palazzo Vecchio and the History of Museums," in M. Beretta, P. Galluzzi, and C. Triarico, eds., *Musa Musaei: Studies on Scientific Instruments and Collections in Honour of Mara Miniati* (Florence: Olschki, 2003), 191–197.
16. Oronce Finé, *De Solaribus Horologiis et Quadrantibus* (Paris, 1560), 155–163.
17. Museum of the History of Science, inventory no. 53211.
18. Ibid., inventory no. 44721.

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The Web of Knowing, Doing, and Patenting: William Thomson's Apparatus Room and the History of Electricity

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Introduction

The periodization of the history of electricity seems to have posed no major problems to historians of science. Scholars agree that around 1800 there was a turning point: whether the focus is on Coulomb and Poisson, or on Volta and his electric battery, or both, events after 1800 presented new opportunities and new challenges, marking a discontinuity with the earlier period.[1] A similar agreement exists concerning the beginning, around 1880, of what was called by contemporaries the "age of electricity."[2] The literature available on electrification in Western countries after 1880 has established the notion that the most significant technological developments associated with electricity began around that date, marking another discontinuity with previous events.[3]

A consequence of this agreed, if seldom problematized, periodization has been to convey the view that the tools appropriate for treating the history of electricity prior to 1800 are mainly those provided by the history of science, although the history of technology and economics should be brought in when addressing the period after 1880. Over the past few decades, a host of studies carried out according to methodologies inspired by cultural and social history have helped to reshuffle the traditional borders between the history of science and of technology; but the periodization of the history of electricity has not been affected accordingly. One consequence has been that the period from 1800 to 1880, while treated in a number of excellent studies,[4] has retained the status of a kind of magmatic interlude: a period when many crucial developments took place, whose connections with the rest of the story—the one before 1800 and the one after 1880—remain problematic.