

## Chapter 2

# Archaic Astronomical Instruments

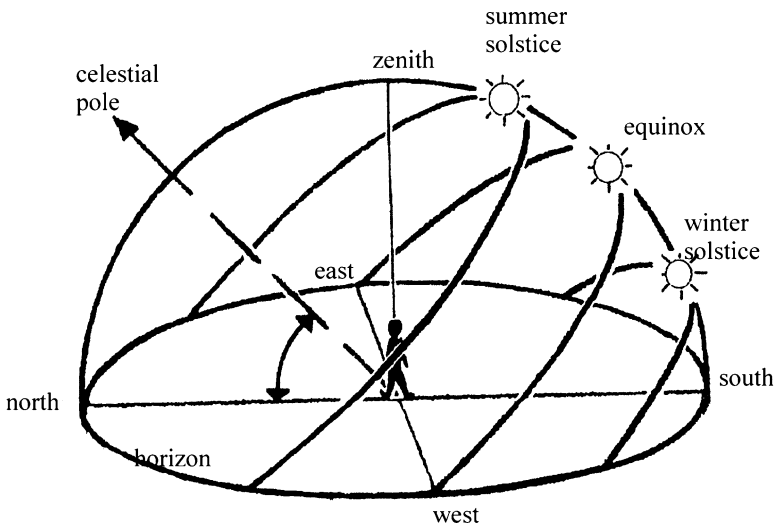
The oldest astronomical instrument is the *naked eye*, with which the courses of the celestial objects were observed. Since time immemorial, people have noticed that the celestial bodies rise at the eastern horizon and set at the western horizon. They have also noticed that some stars never set and that all stars circle around a fixed point in the northern sky (at least on the northern hemisphere, where the oldest civilizations were. See Fig. 2.1). Already in ancient times, this point was conceived of as the end of the celestial axis. More on the celestial axis in Chap. 5.

The rhythm of day and night is determined by the appearance and disappearance of the sun. That in summer the sun is higher and a longer time in the sky than in winter is governed by another rhythm, that of the year. One can observe that every day the sun rises and sets at another point at the horizon, in summer in the eastern, respectively, and western sky further to the north, and in winter more southward (always on the northern hemisphere, where the ancient civilizations were). The sun reaches its northernmost position on the first day of summer, when the day is longest. This is called the summer solstice. The southernmost position of the sun is reached on the first day of winter, when the day is shortest. This is called the winter solstice. Twice a year, the points of sunrise and sunset lie exactly opposite to each other, due east and due west, respectively. On these dates, night and day are of equal length. These days are called the equinoxes. The circles of the daily orbit of the sun stand perpendicular to the celestial axis. The inclination of the plane of the sun's daily orbit in relation to the horizon varies from place to place, according to the location of the observer. The farther to the south, the higher the sun, and the farther northward, the lower (always on the northern hemisphere. See Fig. 2.2). More on this phenomenon, as seen from a flat earth, in Chap. 5.

The moon has a rhythm of its own, characterized by its monthly passing through the subsequent stadia of new moon, waxing crescent, first quarter, waxing gibbous, full moon, and back again to waning gibbous, last quarter, waning crescent, and new moon. The moon too, stands high or low in the sky in a monthly rhythm that is called the tropical month. Sometimes the strange phenomena of partial or total lunar and solar eclipses take place. The stars are always in the same and fixed mutual positions. From ancient times, people have divided the celestial vault into constellations, which made the topography of the sky easier. The velocity with which the stars move along the sky differs from that of the sun and the moon, making us see



**Fig. 2.1** Stars circling around the celestial axis on a recent time exposure (photograph by Antonio Fraga, composition, and Gabriel Vazquez, circumpolar stars)



**Fig. 2.2** The daily orbit of the sun in the different seasons

different constellations as the seasons pass. Only the constellations that never set remain visible during the whole year. Part of the unchanging starry sky is occupied by a capriciously shaped and softly shining belt, the Milky Way. Seven or eight celestial bodies (depending on whether the morning star is taken to be identical with

the evening star) do not have a fixed position on the celestial vault. These are the so-called planetary stars, or planets. They are not at arbitrary places in the sky, but move within the limits of a belt of constellations, the Zodiac.

As a result of careful and regular observations of the sky over many generations, all kinds of regularities have been recorded, for instance, the way lunar and solar eclipses appear. An example can be seen in Chap. 3, Table 3.2, which shows the lunar and solar eclipses that Thales could have observed during his lifetime in Miletus. These eclipses move like garlands through the calendar. Another example is the cycle of Meton. This is the cycle of 235 synodic months (the time between two subsequent new moons), which is approximately 19 years. At the end of this cycle, the sun and the moon, in relation to each other and to the stars, are in virtually the same position as at the start. This cycle is named after Meton of Athens, who introduced it in 432 B.C. to improve the calendar.

From ancient Mesopotamia, we possess an enormous amount of observations, descriptions, and predictions of the rising and setting of the celestial bodies and their courses along the firmament, preserved on clay tablets. The Babylonians were well-versed observers and had achieved excellent results. In the second century A.D., Ptolemy, in his *Almagest*, used the systematic Babylonian registrations of the movements of the sun, moon, and planets, dating as far back as the time of Nabonassar (747 B.C.).

From the Presocratics, on the contrary, we hardly know of any observations of this kind. One of the few exceptions is a report by Pliny of an observation, made by three ancient observers, Hesiod, Thales, and Anaximander, of the time the Pleiades set (*Naturalis historia* XVIII: 213, see also DK 12A20). According to Hesiod, it was the day of the autumnal equinox, which was 30 September in Hesiod's time.<sup>1</sup> According to Thales, it was 25 days, and according to Anaximander, it was the 31st day after the autumnal equinox (which was 29 September in their days).<sup>2</sup> As regards Hesiod, Pliny's source is a lost book on astronomy that is ascribed to him. In his *Works and Days*, Hesiod says no more than the following: "When the Pleiades set at the end of the night, then it is the right time to plough," and: "When the Pleiades, Hyades, and Orion set, remember that it is the season to plough" (*Works and Days* 681–682 and 432–433). Pliny adds the observations of two later astronomers: according to Euctemon, the Pleiades set the 44th day after the autumnal equinox (which was on 28 September), and according to Eudoxus on the 48th day after the autumnal equinox (which was on 28 September). If we take the year 700 B.C. for

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<sup>1</sup> Before 1582 A.D., the dates of the equinoxes and solstices shift about one day per 128 years on the Julian calendar. This was corrected by Pope Gregory's calendar reform, which resulted in an error of only one day in about 3,000 years. Moreover, to eliminate the 10-day error that had developed since the church council of Nicea, in the same year, 1582 ten days were passed over so that 4 October was followed by 15 October. This is why Table 2.1 differs from that in Couprie (2003: 181), where 23 September was taken as the date of the autumnal equinox throughout.

<sup>2</sup> White reads for Anaximander: "on the 29th [day from the equinox]" (2002: 10). This makes, however, only a few minutes difference: on 28 October 560 B.C., the sun rose at 4:33 h, and the Pleiades set at 4:17 h.

Hesiod and his birthplace Ascra in Boeotia ( $23^{\circ}07'E$ ,  $38^{\circ}23'N$ ) as his observation post, 580 B.C. and Miletus ( $27^{\circ}15'E$ ,  $37^{\circ}30'N$ ) for Thales, 560 B.C. and Miletus for Anaximander, 430 B.C. and Athens ( $23^{\circ}44'E$ ,  $38^{\circ}00'N$ ) for Euctemon, and Athens and 350 B.C. for Eudoxus, then the times of sunrise and the true setting of the Pleiades are as indicated in Table 2.1.<sup>3</sup>

**Table 2.1** Ancient dates of the autumnal setting of the Pleiades

Observer	Place	Date of autumnal equinox	Date of observation	Sunrise (universal time)	Pleiades set (universal time)
Hesiod	Ascra	30 September 700 B.C.	30 September 700 B.C.	4:18 a.m.	6:18 a.m.
Thales	Miletus	29 September 580 B.C.	24 October 580 B.C.	4:27 a.m.	4:30 a.m.
Anaximander	Miletus	29 September 560 B.C.	30 October 560 B.C.	4:33 a.m.	4:07 a.m.
Euctemon	Athens	28 September 430 B.C.	11 November 430 B.C.	5:02 a.m.	3:42 a.m.
Eudoxus	Athens	28 September 350 B.C.	15 November 350 B.C.	5:07 a.m.	3:30 a.m.

The last column in Table 2.1 shows the different time of the true setting of the Pleiades. Because of the light of the rising or setting sun, stars are invisible some time before and after sunrise and sunset. Therefore, the ancient astronomers noted the first and the last moment of visibility of a certain rising or setting star. In relation to the rising sun, these are called the heliacal rising and the cosmical setting. The data of the cosmical setting are (with an insecurity margin of 2 days to both sides) as follows: Ascra 6 November 750 B.C., Miletus, 7 November 580 B.C., Miletus 7 November 560 B.C., Athens 8 November 430 B.C., and Athens 9 November 350 B.C. Euctemon's and Eudoxus' figures seem to refer to the cosmical setting of the Pleiades.<sup>4</sup> They correspond rather well to the duration of the astronomical dawn, which is about 1 h and a half for latitudes between  $36^{\circ}$  and  $44^{\circ}$  (see Neugebauer 1922: 21, Table 11). Wenskus has tried to explain the data for Thales and Anaximander, which are, respectively, “um etwa zehn Tage zu früh” and “etwa eine Woche zu früh,” by suggesting that in the case of Thales we have to read 35 days after the autumnal equinox instead of 25 and that in the case of Anaximander

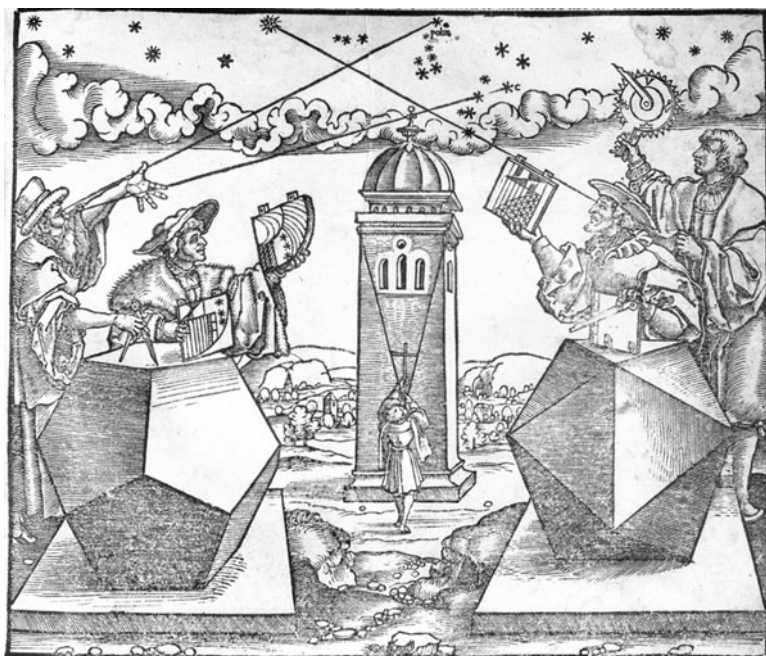
<sup>3</sup> This table is made with the help of the computer program *Redshift 5.1* (2005), and compared with Neugebauer for the days of the equinox (1922: 49, Tafel 19).

<sup>4</sup> Information from USHA-member Rob van Gent, according to the computer program *Planetary, Lunar, and Stellar Visibility 3.0*. Pannekoek, discussing Hesiod, gives on one and the same page the dates for the cosmical setting of the Pleiades as 12 and 3 November, the last the same as Wright (Pannekoek 1961: 95; Wright 1995: 18). Dicks (1970: 36) has 5–11 November; Bickerman (1980: 112) has 3–5 November for latitude  $38^{\circ}$  and the years 500–300 B.C.; Wenskus (1990: 250) has 4–6 November for 700–300 B.C. (see also p. 49), and elsewhere: “Ende Oktober – Anfang November” (1990: 176). White has November, and remarks: “the extended size of the cluster makes its rising and setting impossible to determine precisely” (2002: 10).

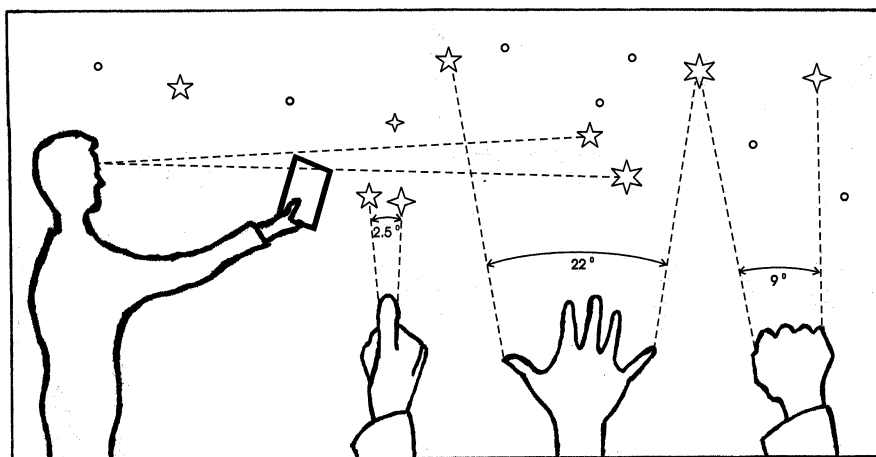
we must suppose that he had very sharp eyes and was able to see the Pleiades set less than half an hour before sunrise (1990: 53, see also 52 and 60). Although the notion of “cosmical setting” is somewhat vague and depends on the sharpness of sight of the observer, it is certainly impossible to see stars of that magnitude set half an hour before sunrise, even if one takes into account that the sky at the western horizon is still rather dark when the rose-fingered dawn announces the rising sun in the east. I tend to think that Thales and Anaximander, on the contrary, were not concerned with the cosmical setting but tried to fix the precise moment at which the rising of the sun and the true setting of the Pleiades at the western horizon coincide. If Pliny’s report is right, they must have been able to calculate in one way or another the elapsed time from the last moment the Pleiades were visible until their true setting, when they are no longer visible. We may conclude that, according to Pliny, Thales’ account was better than that of Anaximander. The resulting date for Hesiod, however, is rather strange because at the autumnal equinox the Pleiades set almost 2 h after sunrise. Perhaps he was not yet able to fix the date of the equinox or to calculate the time the Pleiades actually set. As regards the strange figure given for Hesiod, Wenskus has to admit that “die Hesiod zugeschriebene Angabe ungenau” is (1990: 51–52).

Already in ancient times, observers have tried to improve the accuracy of the results achieved with the unaided eye. The first tool is the *human body* itself. The altitude of a celestial body above the horizon, or the angular distance between two stars, can be measured by means of the finger (the *digit*), the thumb (the *inch*), the fist (the *palm*), the stretched fingers (the *span*), and the forearm from the elbow to the middle fingertip (the *cubit*), and so on. Ptolemy cites observations like these: “In the year 82 of the Chaldeans, Xanthicus 5, Saturn was two digits below the Virgin’s southern shoulder”; “In the year 75 according to the Chaldeans, Dios 14 in the morning, Mercury was half a cubit on the upper side of the southern Balance” (*Almagest* XI 7 and IX 7). We may assume that the ancient Greeks also measured distances on the firmament in this way. The person on the left of Fig. 2.3 shows that this method was still used much later. Figure 2.4 shows other examples, redrawn after a more recent handbook.

The Egyptians used the human body in yet another way to locate a point in the sky. In the tombs of Ramesses VI, VII, and IX, a kind of star clock is painted, consisting of 24 sitting men (one for the first, and one for the 16th day of each month), above whom stars are drawn, as in Fig. 2.5. The sitting person, obviously an aide of the observer, had to sit all night with his back to the south (or better: the line between the observer and his assistant had to be the north–south line – we would say the meridian of that place). The rows on the right indicate the hours of the night, and the columns behind the sitting man the various positions of the stars, for instance “the star of Sothis (Sirius) on top of the left shoulder.” This method of determining a position has become obsolete, not only because of its inherent inaccuracy but perhaps also because it must surely have been a nuisance for the aide of the astronomer to have to sit still all night (see Clagett 1995: 64–65). Bruins has made the interesting suggestion that “the ‘target figure’ of the star clocks is *not an assistant* of the observing astronomer, but the astronomer *himself*! The painter depicted the seated astronomer and *what he sees* is, independently, drawn ‘behind



**Fig. 2.3** Several manners of measuring distances at the firmament on an engraving from 1533 A.D. (picture by the courtesy of Adler Planetarium & Astronomy Museum and Cambridge UP)



**Fig. 2.4** Some more examples of measuring angles between stars (freely after Klepešta and Růkl 1969: 70)

him' in the charts" (1965b: 173). However, his interpretation of the indications "opposite the heart," "on the left shoulder," etc., as "mnemotechnic expressions" sounds not very convincing (cf. 1965b: 174).



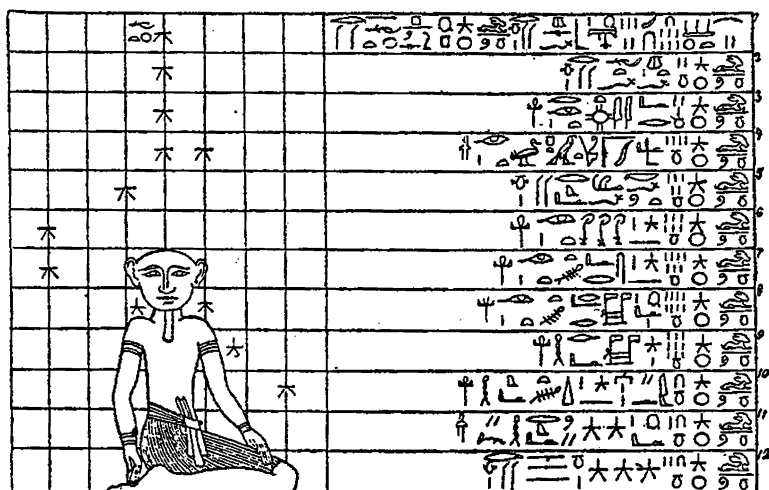


Fig. 2.5 Part of the star clock in the tomb of Ramesses IX (Sloley 1931: 169, Fig. 3)

In the following description of genuine instruments, by which I mean *manufactured tools*, I confine myself not only to the instruments that were used by the ancient Greeks, or with which they could have been acquainted, but also to the period before the discovery of the sphericity of the earth. The instruments that were developed after that have been described sufficiently elsewhere and are of less interest for the scope of this book. It is strange that this subject is scarcely treated in studies on archaic astronomy. Perhaps one reason is that although the Babylonians were experienced observers of the heavens, we do not know whether they made use of any instrument other than the gnomon. Observing instruments are neither mentioned in the texts nor found in the excavations, not even a water clock (see Steele 2008: 45). Although Egyptian astronomy is generally said to be poor as compared with that of the Babylonians, at least three kinds of astronomical instruments have been found in Egypt, as we will see. However, this may be, most authors start with the instruments of Ptolemy. In this respect, even the standard work of Kelley and Milone (2005) has a serious lacuna.<sup>5</sup> Moreover, Dicks' article and Gibbs' chapter on ancient astronomical instruments, in spite of their titles, give less than one would expect (Dicks 1954: 77–85; Gibbs 1979: 39–59). The same holds for Thurston's chapter on the astronomer's tools where mainly later and more sophisticated (and especially Chinese) instruments are treated (1994: 26–44).

The person on the left in Fig. 2.4 uses a little *piece of board* to compare the angular distances of stars. A similar instrument is described by Simplicius (*In Aristotelis De caelo commentaria* 504.16 ff.), explaining how one can easily see that the moon does not always have the same angular diameter. A disk held at a certain distance from our

<sup>5</sup> Kelley and Milone use another definition of “Archaeoastronomy” than in this book, namely, “the practices of pretelescopic astronomy” (2005: vii).

eye sometimes needs a diameter of 11 in. to cover the moon but 12 in. at another time of the year. This is not to be confused with the well-known phenomenon that the moon looks bigger at the horizon than in the zenith, and which can be shown by the same instrument to be an optical illusion. In one of the following sections, we see how a similar tool can also be used to measure the angular diameter of the sun.

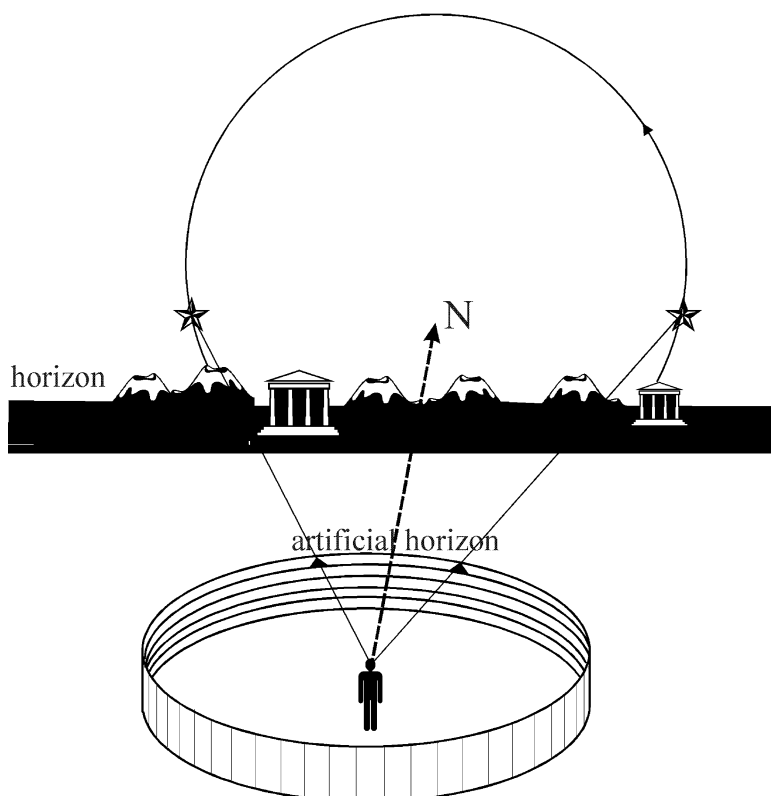
One is well advised not to study the sun by direct observation because of the danger of eye damage. To observe the sun, and solar eclipses in particular, people used the reflection on *the surface of a liquid*, for instance olive oil, poured into a bowl, as described by Seneca (*Naturales Quaestiones*: 1, 11.3–12.1). The reader can find out for himself that it is possible, after some time of eye accommodation, to observe a distinct reflection of the sun disk, even at noon. I used this method myself, with perfect results, to observe the partial sun eclipse on 1 August 2008 at Maastricht. In his allegory of the cave, Plato hints at this method when he says that the prisoner, who is freed from the cave and arrives at the surface of the earth, sees the sun “without using its reflections in water or another medium” (*Republic* 516b). Elsewhere he speaks of the risk people run to injure their eyes when looking at a solar eclipse, “unless they study its image in water or something like it” (*Phaedo* 99d). Another way to observe the sun, and in particular a solar eclipse, is with a *camera obscura*, where the light of the sun is captured through a little hole, throwing an reversed image on the opposite wall. Aristotle seems to hint at it somewhere, but it is doubtful whether the Presocratics were already acquainted with this method (*Problems*, book xv, Chap. 6). Thales could have used one of these methods for his observations that led to the prediction of a solar eclipse.

To avoid the unevenness of the real horizon, people may have used an *artificial horizon*, like the little circular wall in Fig. 2.6. With this device they could, for instance, determine the north. From the center of the circle, the observer notes where a certain star rises above the wall, and he puts a mark there. In the same way, he puts a mark where the star sets. The bisector that divides the angle from the observer to the marks into two equal parts will point to the north.

Somewhere – though not in a book on astronomy – Aristotle mentions the *sighting tube* (*Generation of Animals*: 780b 19–2 and 781a 9–12). A sighting tube (Greek: *διόπτρα*, but Aristotle speaks of an *αἰλός*) is a hollow tube, put on a stand, a kind of telescope without lenses (see Evans 1998: 33 and 34). A sighting tube facilitates the observation of stars at daybreak or in the evening twilight, by keeping out the atmospheric light from view. Also at night the observation of stars is improved by the use of a sighting tube (thus Eisler 1949: 314). Observing from the bottom of a deep pit or shaft has the same effect. Even during daytime, the stars are visible with this method, says Aristotle.<sup>6</sup> In the Arabic and European Middle Ages, deep pits were said to be used as observation wells (see Sayili 1953: 149–155). Perhaps this makes sense of the story of Thales falling into a well while looking at the stars. He may have descended into a well on purpose with the intention to make use of its sighting tube function (see Eisler 1949: 324, n. 13).

<sup>6</sup> See also Strabo, *Geographica*, ed. H.L. Jones (Strabo 1923, vol. II: 10).





**Fig. 2.6** Finding north with the help of an artificial horizon

The sighting tube made it possible to find the north in another way as well. If one points the tube toward an arbitrary star, this star will disappear from sight after a certain time, because of the turning of the celestial vault. If one points it toward the Polar star, this will remain visible all night. Since the Polar star, because of the precession, was in archaic times further removed from the actual celestial pole than today, another star was nearer to the pole. In Anaximander's time, a star just at the limits of human visibility stood almost at the north celestial pole (FK3037, magnitude +6.00, at about  $89^{\circ}27'$ ), but the ancients probably preferred Kochab in the Big Dipper (magnitude +8.00, at about  $83^{\circ}09'$ ). To find the north, one would have to point the sighting tube – of suitable size and fitted on a stand – in such a way that that star described a small circle in the visual field of the instrument. The center of this circle is the north pole of the heaven (Eisler 1949: 313). Figure 2.7, the original of which dates from more than three and a half centuries before the invention of the telescope in The Netherlands, shows that in the Middle Ages the sighting tube was still in use. In Chap. 16, we discuss a rather spectacular measurement with the help of such a sighting tube.

**Fig. 2.7** The personification of astronomy with a sighting tube. Drawing (c.1880 A.D.) after medieval manuscript (1241 A.D.). For the original, see [http://www.manuscripta-mediaevalia.de/hs/katalogseiten/HSK0523b\\_a040\\_jpg.htm](http://www.manuscripta-mediaevalia.de/hs/katalogseiten/HSK0523b_a040_jpg.htm). (© Hermann, [www.editions-herman.fr](http://www.editions-herman.fr))



Diogenes Laertius relates that Thales maintained that the diameter of the sun equals  $1/720$ th part of its orbit (and that the same holds for the moon).<sup>7</sup> This is confirmed by Apuleius (DK 11A1(24) and 11A19). In other words, 720 suns placed in a row add up to the full circle of its daily orbit. This is correct because the angular

<sup>7</sup> Gobry, who reads this text as “Selon Thalès (...) la course de la lune est le cent vingtième de celle du soleil”, is twice mistaken (2000: 172).

(or apparent) diameter of the sun (which is the angle between our eye and the both ends of the sun's diameter) equals approximately half a degree (see Fig. 2.8). As with all doxographical accounts on Thales, we have to be careful about the truthfulness of this statement. To measure the angular diameter of the sun implies that Thales would have developed the idea that the celestial bodies pass underneath the earth during their daily course along the firmament, making a full circle. This idea, however, is not consistent with his world picture, at least as far as we are acquainted with it. As we discuss in Chap. 4, Aristotle says that according to Thales, the earth floats on water like a piece of wood. This representation is difficult to combine with the idea of celestial bodies making full circles around the earth, which implies that the earth hangs freely in space instead of floating on water. The unsupported earth is, as we see in Chap. 8, Anaximander's conception. If the account on the measurement of the angular diameter of the sun is based on truth, then Anaximander probably has to be credited with this achievement rather than Thales.

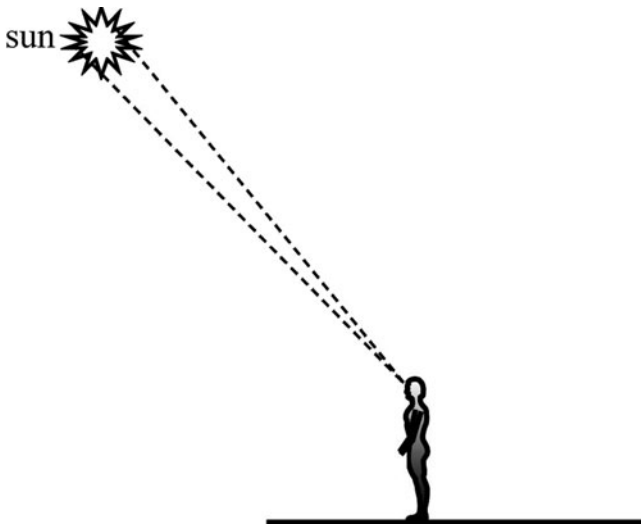
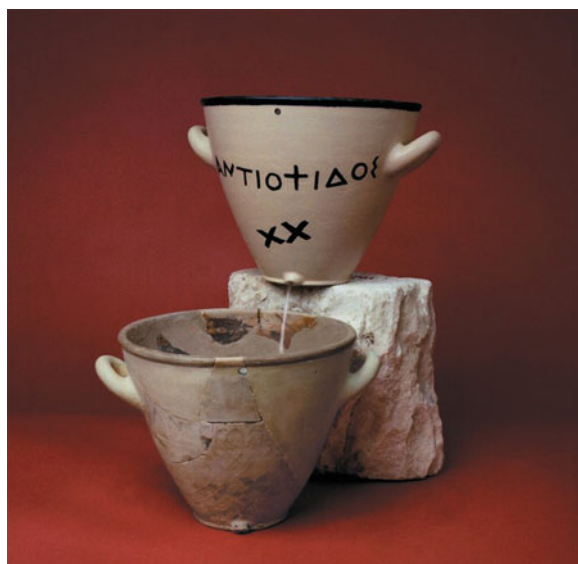


Fig. 2.8 The angular diameter of the sun

He could have made this measurement with the help of a *water clock*, the so-called *clepsydra* (κλεψύδρα, “water thief”. See Fig. 2.9). This instrument was already used by the Egyptians about 1350 B.C. and even earlier (see, e.g., Lull 2006: 137–139; Clagett 1995: 65–82 and plates III. 21a–35). The principle of a *clepsydra* is the same as that of an hourglass. Its use is described by Cleomedes in the second century A.D. The picture shows a primitive Greek *clepsydra*, consisting of two containers, one placed above the other. The upper vessel is continuously filled with water that slowly drains away into the lower vessel in a steady stream. When the lower vessel is full, it is replaced by an identical empty one, so that a measurement of time in equal units is achieved. Cleomedes describes the experiment as follows: “During the time from the first appearance of the sun above the

eastern horizon until the time the whole sun is visible above the horizon, one vessel of the water-clock will be filled. When one lets the water stream out day and night, until the next sun rises above the horizon, about 750 vessels will have been filled. Therefore, the diameter of the sun equals 1/750th part of its entire orbit” (*De motu circulari corporum celestium* 2.75, at p. 136).<sup>8</sup> Cleomedes’ result differs from the 1/720th part mentioned by Diogenes Laertius. This, however, will be due to the intrinsic inaccuracy of the measuring method used (see Dicks 1954: 84: “it was liable to constant error”).<sup>9</sup>

**Fig. 2.9** A simple Greek *clepsydra* (water clock) (photograph by the courtesy of Agora Excavations, The American School of Classical Studies at Athens)



It is interesting to compare Cleomedes’ *clepsydra* with an Egyptian specimen of 14 in. height, found in Karnak and dating from about 1400 B.C. This *clepsydra* was supposed to empty in one night. On the inside of the vessel, inscriptions are made that indicate the water level for the hours of the night at different times of the year (see Fig. 2.10). The length of the night at Karnak varies during the seasons between 610 and 820 min. Although we would say that it does not matter whether one

<sup>8</sup> Wasserstein tries to make acceptable that Thales would have used another method than that with the *clepsydra*, since his result differs from that of Cleomedes (1955: 114–116). Thales’ result of 1/720, Wasserstein says, is obviously inspired by the hexagesimal system, in which the circle is divided in 360°. His argumentation, however, is not convincing. Given the inaccuracy of the measuring method, Thales – or whoever performed the calculation – could very well, for instance for aesthetic reasons, have brought his results in line with the hexagesimal system. Moreover, Wasserstein gives no indication of what other method Thales should have used.

<sup>9</sup> The *clepsydra* on Fig. 2.9 is in the Athenian Agora Museum. It is said to be used to control the length of a testimony in the Dikasterion. When the water stopped flowing, everyone yelled “sit down” to the speaker (information by Robert Hahn). Of course, this does not exclude the possibility of using the *clepsydra* for astronomical purposes as well.

measures the hours of the day or those of the night, an inscription on the *clepsydra* tells that it was meant to measure the hours of the night. Perhaps its primary use was to let the priests know the exact time to say prayers.<sup>10</sup> When we compare this instrument with Cleomedes' *clepsydra*, we may conclude that it emptied about 375 times faster than the Karnak *clepsydra*, which is an amazing difference. The Egyptian *clepsydra* must have had a very small aperture of less than one millimeter in diameter. The Egyptians probably put a metal (golden) orifice with the desired diameter into the aperture of the *clepsydra* (Cotterell and Kamminga 1990: 62; Sloley 1924: 45, n. 5). Given the volume of the Karnak *clepsydra* of about 22 l, and the volume of a droplet of 50  $\mu$ l, one may calculate that ideally speaking, the water had to drop out at a steady rate of about ten drops per second (Turner 1984: 46; Sloley 1924: 45). It would have been a question of trial and error to find the diameter that produced the right speed of the outflowing water.

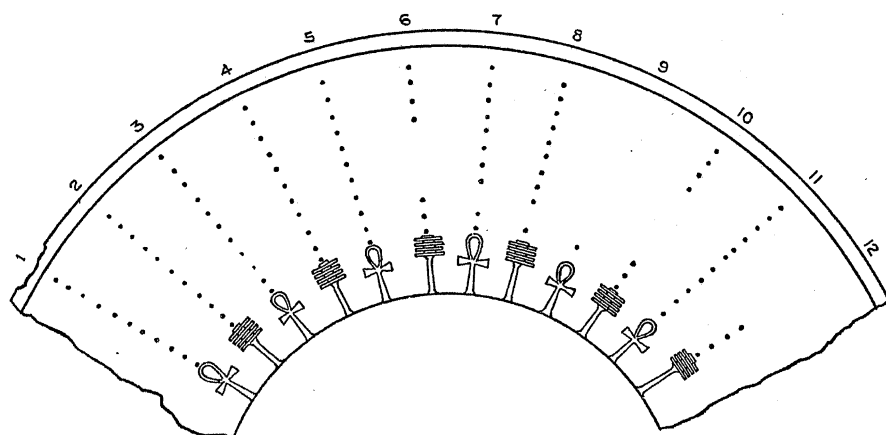


Fig. 2.10 The month scales on the inside of the Karnak *clepsydra* (Sloley 1924: 46)

Another problem was that the velocity of the water flow decreases as the water level drops. The Egyptians tried to solve this problem by making the vessel conical, the lower diameter being smaller than the upper diameter, so that the lower water pressure was compensated by the smaller amount of water flowing. As the water pressure is reduced to zero when the water-level reaches the bottom of the vessel, they made the aperture a bit above the bottom. Recent calculations and experiments have resulted in the conclusion that “the clock would have been accurate as far as the Egyptians were concerned” (Cotterell and Kamminga 1990: 63, and especially Fig. 3.10).

According to White in a recent handbook, Anaximander could have measured the apparent diameter of the sun in another way, using a tool similar to the piece of board already described above. He writes: “if the disk of a cup or plate held at arm’s length covers the rising sun, then the disk can be used to measure the horizon by counting how many of the diameters of the cup or plate it spans” (2008: 109).

<sup>10</sup> Information by Robert Hahn.

In order to prevent eye damage and to get a better picture of the sun disk, one has to better wait until the sun is somewhat clouded. White recommends using an artificial horizon like that in Fig. 2.6 to provide for a perfect circle. However, in what follows, he makes the procedure needlessly complicated by suggesting a pointer turning along the horizon. The easiest way would be, instead of holding it in the hand, to put a disk of appropriate size on an artificial horizon while standing at its center and divide the circumference of that horizon by the diameter of the disk. Just like with the use of the *clepsydra*, this procedure avoids calculating with  $\pi$ . On the other hand, it presupposes some knowledge of the laws of perspective to elucidate that the angular diameter of the sun has to its circular path around the earth the same ratio as the diameter of the disk to the circle of the artificial horizon.

Apparently, White did not perform the experiment he describes himself. Otherwise, he would have noticed that not “the disk of a cup or plate,” but a vitamin pill (with a diameter of about a quarter of an inch) held at one arm’s distance will cover the sun. Probably, this is the reason why he states that “the results are bound to be wildly inaccurate” (2008: 109). On the contrary, they are acceptably accurate, as the reader can easily check by performing the experiment. They remain within an acceptable range, comparable with that in measuring with the *clepsydra*. In a somewhat older handbook, it has already been stated that “(the) value of  $\frac{1}{2}^\circ$  (...) can be ascertained by the most simple observation” (Pannekoek 1961: 120). The error definitely cannot be a factor 4, as White surmises when he conjectures that Anaximander took the angular diameter of the sun to be  $2^\circ$  instead of a half degree. White makes a curious mistake when he writes that the result is impoverished because “the atmosphere makes the sun appear larger on the horizon than in the sky” (2008: 109). As already explained above, this mistake can be exposed with the help of the same tool. The disk that covers exactly the sun high in the sky will be seen to cover exactly the sun at the horizon as well. Moreover, it is not the atmosphere that causes this illusion. This is a misunderstanding introduced by Aristotle (*Meteorologica*: 373b12–13), as can be read in any book on optical illusions.<sup>11</sup>

The *gnomon* (γνῶμων) is usually considered as the most important instrument of archaic astronomy. On the operation of sundials, many books have been written.<sup>12</sup> Usually, however, relatively little attention is paid to the simplest and oldest sundial, the upright gnomon. A gnomon is nothing but a stick or staff put vertically into the ground, the shadow of which can be studied. Any other vertical object, an obelisk for instance, or even the upright human body itself may function as a gnomon as well.<sup>13</sup> Diogenes Laertius says that Anaximander invented the gnomon (DK 12A1(1)). This report must be false, since the gnomon had been in use for centuries all over the world, for instance in Mesopotamia. The oldest records of Babylonian observations with the help of a gnomon, dating from 687 B.C., are preserved in a number of clay

<sup>11</sup> For quick information, see the article “Moon illusion” in Wikipedia.

<sup>12</sup> A good introduction still is, for instance, Mayall and Mayall (1938). A survey of ancient sundials can be found in Gibbs (1976).

<sup>13</sup> See, e.g., Pliny’s description of the obelisk that was erected on the Campus Martius in *Naturalis historia* XXXVI, 72.



tablets that are called <sup>MUL</sup>.APIN, after their first words. They contain, among other things, tables indicating when the shadow of a standard gnomon has a certain length.<sup>14</sup> Herodotus says somewhere (*Histories* II 109) that the Greeks learned the use of the gnomon from the Babylonians. Probably, then, we have to explain Diogenes Laertius' report in this way that Anaximander introduced the gnomon from Mesopotamia into Greece.<sup>15</sup> Diogenes Laertius and others also report that Anaximander had erected in Sparta an instrument for measuring the hours, and that he used the gnomon not only to measure the time but also to determine the solstices and the equinoxes (DK 12A1(1), DK 12A2, and DK 12A4).

Usually it is said that the gnomon is in the first place an instrument for telling the time of the day. So, for instance, Van der Waerden says: "Der Hauptzweck des Gnomons ist, aus dem Gnomonschatten die Tageszeit zu erkennen" (1965: 254).<sup>16</sup> It may be doubted, however, whether this is as simply true as it sounds. Imagine that you walk around with a stick and want to know the hour of the day. You put your stick perpendicularly in the sand and study the length of its shadow. What does it tell you? All you know is that at different times of the day the shadow has different lengths and that the length of the shadow varies with the seasons. I think you had better throw your stick away, remember where the south is and look directly where the sun stands. Before we discuss a method to handle the problem of telling the time with an upright gnomon by fixing it at one place, we deal with the use of the gnomon as an astronomical instrument.

Pedersen and Phil say: "Even with a simple gnomon it is possible to perform a large number of measurements fundamental to astronomy" (1974: 42).<sup>17</sup> Nevertheless, in spite of its various uses, the gnomon remains a rather limited astronomical instrument because it is, so to speak, the instrument of the day, whereas ancient astronomy is mainly the science of the night sky. Local noon is the only time of the day that can be determined with a gnomon rather precisely, and in different ways, as we see in due time. When employed to find out local noon, the gnomon functions not only as a time indicator but also as an astronomical instrument because it determines the north-south line, since at local noon the sun is at its highest and stands exactly in the south. The first method is to study carefully the shadow of a gnomon during the day and note its smallest length. At that moment, the gnomon's shadow lies exactly on the meridian of the observer, which is the circle that runs through both poles of the earth. Of course this is something the ancients could not know because it presupposes knowledge of the sphericity of the earth. This method, however, is too inaccurate, as differences in length of the shadow are very hard to

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<sup>14</sup> <sup>MUL</sup>.APIN means as much as "the Plough star." It is a small constellation, consisting of our constellation Triangulum and the star  $\delta$  Andromedae.

<sup>15</sup> In a recent study, Haase has held the somewhat strange opinion that Herodotus' text must be read in the sense that Anaximander "im Unterschied zum altorientalischen Verständnis dieses Messtechnischen Instruments den Gnomon erstmals als *Medium* begriff" (2008: 18, my italics).

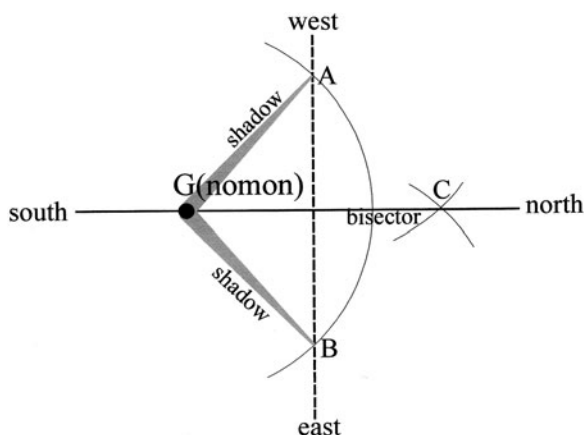
<sup>16</sup> I did it myself in Couprie (2003: 185).

<sup>17</sup> See also Sarton (1959: 174): "A relatively large amount of precise information could thus be obtained with the simplest kind of tool."

perceive during a considerable time around noon, and especially in winter, when around noon during more than an hour the differences in altitude of the sun are no more than  $1^\circ$ . This handicap bothers all instruments that are based on an upright pointer, such as the Egyptian *merkhyt* that is treated hereafter.

The second method to determine noon is more precise and consists of bisecting the angle between an arbitrary morning shadow and an evening shadow of the same length. This is shown in Fig. 2.11, where G indicates the point where the gnomon is put into the ground, GA the morning shadow, GB the evening shadow of equal length, and CG the bisector of the angle AGB. An extra check can be made, as the lines CG (north–south) and BA (east–west) must be perpendicular to one another.

**Fig. 2.11** The determination of the noon line with the help of a gnomon

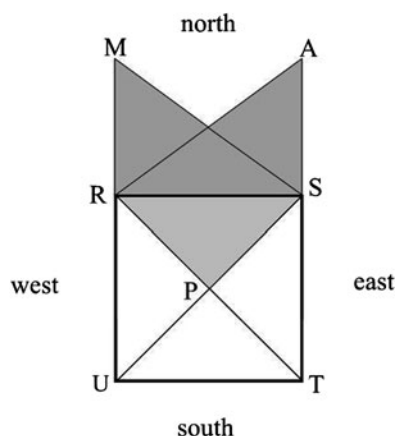


This method is the complement in the day time of determining the north with the help of a rising and setting star, as visualized in Fig. 2.6. However, when you walk around with a stick and want to know when it is noon, these methods will not help you, as noon will be already past when you have finished your observations. With the first method you will notice, when the shadows become longer again, that some time ago it must have been noon, and with the second method you will have to wait for the afternoon shadow to see that some hours ago it was noon. When used to find out noontime, the gnomon functions not so much as a time indicator, but rather as an astronomical instrument determining the north–south line. In addition to Figs. 2.6 and 2.11, at the end of this chapter we discuss another method of finding north.

In a nice little article, Neugebauer has shown how the Egyptians could have used a similar method to orientate their pyramids exactly north–south (1980: 1–3). All they had to do was to take a small but accurately shaped pyramid RSTU with top P (for instance the *pyramidion*, the top of the pyramid itself), and put it roughly on a north–south orientation on a completely flat and horizontal base, where the actual pyramid had to be built (see Fig. 2.12). Then, they had to wait till the morning shadow SMR of the small pyramid was an as-exact-as-possible continuation of the western base UR of the pyramidion to measure the length UM. The same procedure had to be performed in the afternoon, at the time when the shadow RAS was an as-exact-as-possible continuation of the eastern base TS of the small pyramid, and TA could be

measured. If after this procedure UM and TA proved not to be of equal length, they had to turn the small pyramid somewhat, and repeat the procedure the next days, until the shadows were of equal length and the big pyramid could be aligned and orientated. The best measurements can be obtained during the winter months, when the sun is lower on the horizon and the shadow of the pyramid is sufficiently long. However, as it is not so easy to construct a perfectly shaped *pyramidion*, nor a perfectly horizontal floor, and as it is rather difficult to determine whether the shadows are exactly equal in length, this method may suffer from inaccuracies.

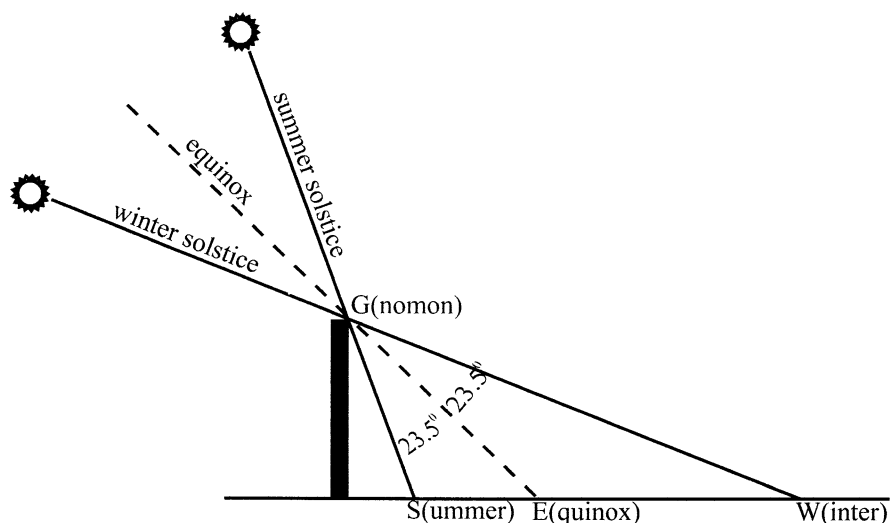
**Fig. 2.12** The north–south orientation of a pyramidion (somewhat adapted after Neugebauer)



Doxographical reports tell us that Anaximander observed the (dates of) the solstices and equinoxes. On the equinoxes, 27 March and 29 September, respectively, in the days of Thales and Anaximander, day and night are equally long. At the summer solstice (29 June in Anaximander's days), the noon shadow of the gnomon is at its shortest, and at the winter solstice (26 December in Anaximander's days), it is at its longest. These dates could only approximately be established, according to Dicks "probably to an accuracy of at best some five or six days" (1966: 29). The reason is that during some days around the solstices, there is hardly any difference in the shadow length at noon.

The angle made by the top of the gnomon and the end of its shadow at the time of the solstices can be measured and will show to be about  $47^\circ$  (see Fig. 2.13). This angle equals twice the inclination of the ecliptic (which is the sun's yearly orbit around the starry sky) in relation to the celestial equator (which is the projection of the earth equator on the sphere of the sky). Acquaintance with the obliquity of the ecliptic presupposes knowledge of the sphericity of the earth. This knowledge, however, is not required for measuring the angle between the shadows of the summer and winter solstices with a gnomon. As Sarton says, speaking about Anaximander: "It was possible (...) from the observations he made with a gnomon (...), to measure the obliquity. Yet, even if Anaximander measured the obliquity, one could hardly say that he understood it" (1959: 292).

On the days of the equinoxes, day and night are of equal length. On these days, the sun rises exactly in the east and sets exactly in the west. With the gnomon, the



**Fig. 2.13** Fixing the shadow points of the equinox and the solstices, and measuring the obliquity of the ecliptic with the help of a gnomon

equinoxes can be found in various ways. The first method is to bisect the angle of the shadows thrown by the gnomon at the summer and winter solstices and to note the day when the shadow reaches the point on the ground found in this way (E in Fig. 2.13). This method is necessarily not very exact, because of the difficulty of measuring the angles at the top of the gnomon and the insecurity of fixing the exact dates of the solstices. The second method is to note on which calendar day the earliest morning shadow and the latest afternoon shadow are just opposite one another. This method too, is not very precise, as it requires a completely smooth horizon on both sides. The third method, which is better, consists of observing on which calendar day the top of the shadow of the gnomon describes a straight line during the day. This line is, for instance, marked on the plate of a Roman sundial (see Fig. 2.16). Contrary to what is sometimes said, none of these three methods presupposes knowledge of the sphericity of the earth, or the idea of a celestial sphere, on which the equator, tropics, and ecliptic are projected.<sup>18</sup> The curves of the

<sup>18</sup> Dicks is wrong when he writes: “the equinoxes cannot be determined by simple observation alone” (1966: 31). And also elsewhere: “The concept of the equinoxes is a more sophisticated one, involving necessarily the complete picture of the spherical earth and the celestial sphere with equator and tropics and the ecliptic as a great circle” (1966: 30). It is also not right to say that “these concepts are entirely anachronistic for the sixth century B.C.” (1966: 30; see also 1970: 45). Of course, the ancient ways of fixing the equinoxes and solstices did not possess the grade of accuracy we would expect nowadays. See also, for instance, Fotheringham: “The determination of the exact date of a solstice remained a difficulty throughout the whole course of ancient astronomy. Even Ptolemy deduced from his own observations a date 38 h later than the true date for the summer solstice” (1919: 168).

shadow of the gnomon top during any day, with the exception of the equinoxes, are hyperbolas, the extremes of which are those of the two solstices. That they are hyperbolas was, of course, not yet known, as is clear from the way in which they are rendered in Fig. 2.16. This does not alter the fact that any ancient observer could observe and draw them.

The gnomon can also be used to determine the observer's latitude by measuring the angle of the shadow at the top of the gnomon at an equinox ( $\angle BGE$  in Fig. 2.14; the latitude depicted is that of Miletus). Of course, this figure makes sense only if one is acquainted with the earth's sphericity.

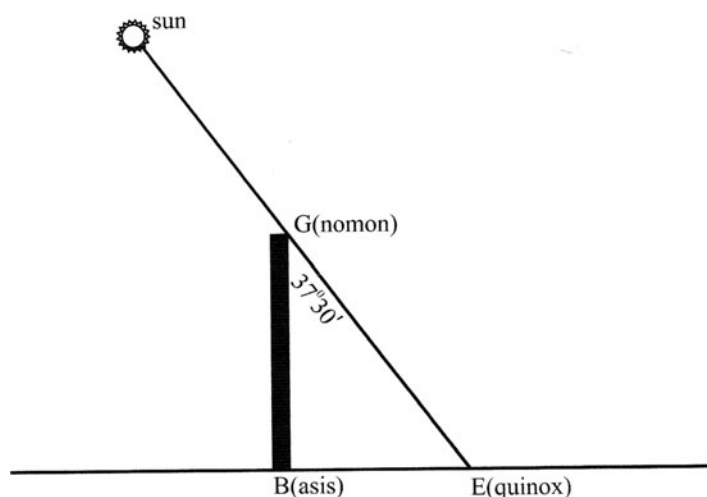
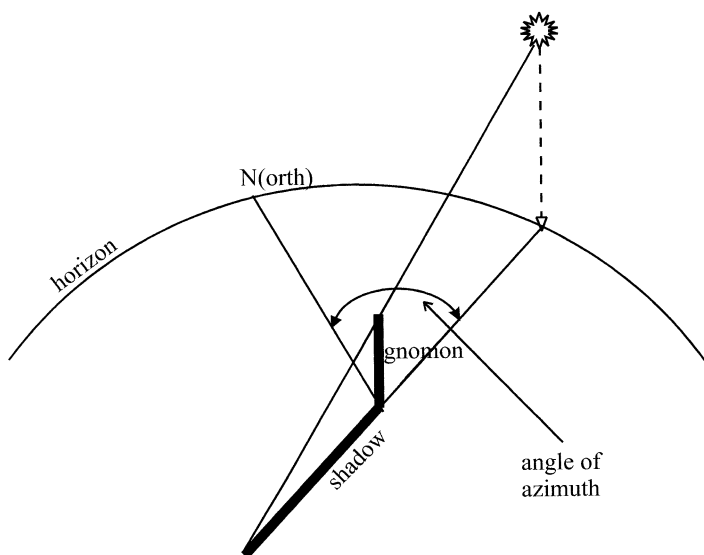


Fig. 2.14 Measuring the observer's latitude with the help of a gnomon

Another possibility is to determine the azimuth of the sun at any time of the day, as in Fig. 2.15. The azimuth is the bearing of an object measured as an angle around the horizon eastward starting from north as the zero point. As is clear from the drawing, one has to determine a north–south line first; the angle between this noon line and the shadow of the gnomon indicates the azimuth. As the stars do not throw shadows, the method at night is somewhat different. To determine the azimuth of a star, you will have to place the gnomon at a certain distance and notice the moment that the star is hiding behind it. Then, the angle of azimuth between the line from the observer to the gnomon and the north–south line can be measured. Combined with measuring the altitude of the star above the horizon with the methods of Figs. 2.3 and 2.4, a rather acceptable determination of the star's position can be obtained. I do not know whether the ancients really used this method. The Egyptians, at least, seem to have preferred the much less precise method of the above-mentioned Rammessian star clocks (see Fig. 2.5), whereas the Babylonians identified the position of the moon and planets by indicating their distances to the so-called Normal Stars (see Steele 2008: 42–44).



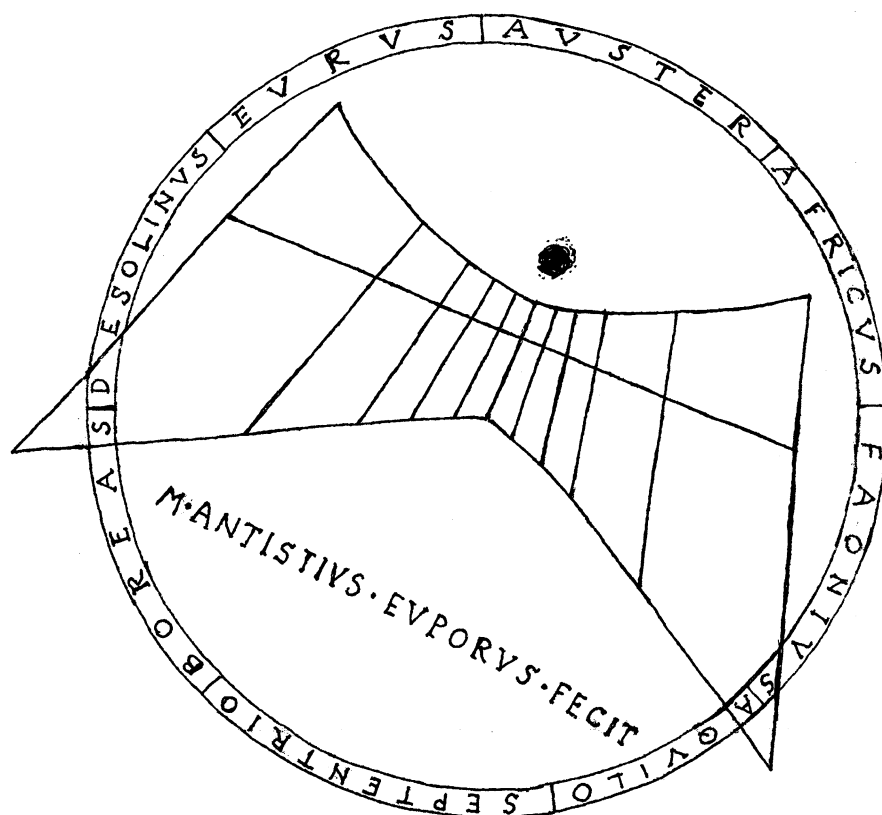
**Fig. 2.15** Measuring the azimuth with the help of a gnomon

Now, let us return to the problem of making the gnomon a time indicator. If you cannot use your gnomon as a time teller when you are traveling around, you may decide to put it permanently somewhere, for instance, at the marketplace. Then, you can construct converging hour lines that indicate the time of the day in different seasons, like on the ground plate of the Roman sundial in Fig. 2.16. The black spot on that picture is the place where a vertical gnomon was erected. The idea is that the tip of the shadow of the gnomon touches the same hour line at different points, depending on the time of the year. This is the way it is described in Kirk et al.: “the ground near the gnomon was calibrated so as to give the time of day” (2009: 103). During the day, the tip of the shadow describes a curve. The outermost curves, drawn at the days of the solstices, are indicated (although not as curves but as broken lines) in Fig. 2.16. On the days of the equinoxes, the shadow of the tip of the gnomon does not show a curve but a straight line, as also indicated in Fig. 2.16 between the two solstitial curves. The doxography tells us that Anaximander erected a gnomon in Sparta to observe the solstices and equinoxes and to measure the hours (DK 12A1(1), DK 12A2, and DK 12A4). If these reports can be trusted, the simplest way to understand them is to suppose that Anaximander drew a pattern of lines similar to that of the Roman sundial on Fig. 2.16.

To construct the hour lines, Anaximander could have proceeded as follows. First, at the day of an equinox, he marked the point of a morning shadow of the top of his gnomon that fell neatly within the ground plate of his sundial (cf. the right end of the equinox line in Fig. 2.16). On the same day, he marked the point of the evening shadow of the same length at the other end of the equinox line. With the help of a clepsydra, he divided the equinox line between these points into equal time portions



(let us assume ten, as in Fig. 2.16), called “hours” (which do not coincide with our hours of 60 min). He observed that equal time portions did not result in equal distances on the equinox line. Subsequently, at the time of the summer solstice, he marked on the curved line of the summer solstice the point of the shadow at noon and then, after the lapse of five successive afternoon “hours” (measured by the clepsydra), the points of the afternoon shadows. He mirrored these points to get the morning hours. Finally, he connected the same hour points on the curve of the summer solstice and on the line of the equinox and thus found the hour points on the curve of the winter solstice (the first and last of which are, on Fig. 2.16, outside the circle of the ground plate). In this way, the hour lines resulted. Now, at whatever day of the year the point of the shadow of the gnomon fell on, e.g., the second hour line in the morning, it was said to be the second hour in the morning.



**Fig. 2.16** Floor of a Roman sundial (first or second century B.C.), with hour lines, equinoctial line and solstitial curves (drawing by Hans Exterkate)

As a commentary on Kirk's lines quoted above Dicks wrote: “there can be no question of the calibration of ‘the ground near the gnomon... to give the time of day’.” This is, as he says, “owing to the fact that the altitude and azimuth of the sun

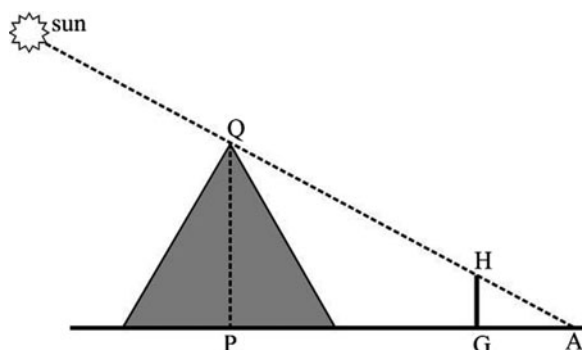
are continually altering, no one set of markings applicable all the year round can be formulated to indicate the division of the day into parts" (1966: 29). Against the background of the reconstruction attempted above, this verdict is too harsh. The division of the day into equal parts ("hours") as shown on Fig. 2.16 would have been sufficient for practical purposes in Anaximander's time. An obvious handicap of the sundial as represented in Fig. 2.16 is that it does not show the early morning and late afternoon hours in summer, when the days are longer. This is because its calibration starts from the equinoctial hours. Drawing more intermediate curves and constructing more hour lines for that season could solve this problem. But then, another problem arises, as the resulting morning hour lines lie before what was called "the first hour." Another evident difficulty is that you will always have to run to the gnomon on the marketplace (or wherever it stands) when you want to know the time of the day. When you are at a certain distance of the marketplace you had better spare you the trouble and simply look at the sun to know approximately what time it is.

The problem of telling the time while walking around with a stick still bothered people as late as the eighteenth century A.D. This is shown in an English almanac of the year 1712 A.D., in which for every single month of the year tables of shadow lengths in southern England with their corresponding morning and afternoon hours were published (see Isler 1991b: 170–171). Borchardt mentions an Egyptian table that, however, is so fallacious that he is not even able to conclude from it in which month the summer solstice must be placed. Another table from Taifa in northern Nubia is so inaccurate that it may only function as a very rough rule of thumb (1920: 27–32). After all, we may not suppose that the ancients used to carry around such tables to translate the length of the shadow of their gnomon into the time of the day.

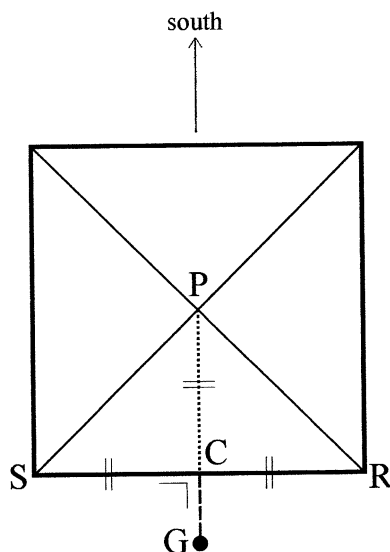
Notwithstanding the above-mentioned proviso, Dicks is basically right when he writes: "observations of the shadow of a gnomon can give only the roughest indication of the time of day, unless the gnomon is so placed that its axis is parallel to the axis of the earth" (1966: 29). The habit of placing the gnomon at an angle, parallel to the earth's or celestial axis (which amounts to the same), however, was developed much later, according to some, in the first century A.D. (Mayall and Mayall 1938: 15). This is the way the gnomon can still be seen on numerous sundials today. When the gnomon is placed parallel to the celestial axis, one reads the shadow of the entire gnomon (not only its top) on a scale.

There is another way of using the gnomon, which is ascribed to Thales, and which at first sight has nothing to do with astronomy. It will, however, appear to have consequences for archaic cosmology, as is shown in Chap. 16. Plutarch tells us that Thales used a gnomon to measure the height of a pyramid. To illustrate his description, I have inserted capitals in his text corresponding with those in Fig. 2.17: "You set up a stick (GH) at the end of the shadow cast by the pyramid, so that by means of the sunbeam that touches both the top of the pyramid and that of the gnomon, you have made two triangles (AGH and APQ). Then you have shown that the ratio of the one shadow (of the pyramid, PA) to the other one (of the stick, GA) is the same as that of the (height of the) pyramid (PQ) to the (length of the) stick (GH)" (DK 11A21, my translation). Thales probably tried to measure the height of the Great Pyramid of Giza (Cheops' pyramid) that is neatly oriented north–south, as we saw.

**Fig. 2.17** How Thales measured the height of a pyramid



Thales would have had to solve two other problems, before he could measure the height of the pyramid.<sup>19</sup> The first problem was that he had to measure the distance AP, whereas P is hidden in the center of the pyramid. To measure this distance (and taking for granted that the pyramid had an exactly square base), Thales would have had to put his gnomon right in front of a point halfway the side of the pyramid, opposite to the sun at noon (the pyramid is, as we have seen, aligned north–south). In Fig. 2.18, which is in plan view, G is the base of the gnomon and P the hidden center of the pyramid, right below its top. Then, the line GP is perpendicular to SR, which it cuts into two equal halves. SCP is an isosceles right-angled triangle, from which follows that  $SC = PC$ . Now, the total length of the shadow of the pyramid is the addition of two lines of known length.  $SC (=PC) + CG$  (in Fig. 2.18) +  $GA$  (in Fig. 2.17).



**Fig. 2.18** Measuring the distance GP

<sup>19</sup> These were the problems Carlo Rovelli's students were confronted with when he asked them to repeat Thales' measurement.

If SR in Fig. 2.18 is the northern base of the pyramid, the line GC points to the south, the direction of the sun at noon. However, if you try to measure the Great Pyramid's shadow, the second difficulty is that during a considerable part of the year the pyramid does not cast a shadow at noon. This is because the angle of its sloping sides is about  $52^\circ$  to the horizontal. Since the Great Pyramid is at  $30^\circ\text{N}$ , the sun at the equinoxes is  $60^\circ$  above the horizon. At the summer solstice, at noon, the sun even gets as high as  $83.5^\circ$  above the horizon. At the winter solstice, the altitude of the sun at Giza is about  $36.5^\circ$ . So Thales had better perform his measurement in winter. Another possibility would be for him to face the west or east side of the pyramid and watch the sun in summer a few hours after its rising or before its setting, when the sun is due east or due west, and not too high in the sky.

An easier way to measure the height of a pyramid is to wait until the shadow is exactly equal to the size of the gnomon. Then, the shadow of the pyramid is also equal to its height. According to Burch this method fails because "a pyramid with a  $45^\circ$  slope (and the Egyptian pyramids are nearly that) casts no shadow at all under the circumstances required by the rule" (1949–1950: 139). Burch is too pessimistic, as the slope of all important pyramids is  $50^\circ$  or more, except one (the north or red pyramid of Snefru) that is  $43.5^\circ$ .<sup>20</sup> The slope of the Great Pyramid is, as we have seen, about  $52^\circ$ . In Thales' time (600 B.C.), the transit altitude of the sun at Giza was  $45^\circ$  on 14 February and 7 November. This means that at those days the shadow at noon fell far enough outside the pyramid to be measured, whereas the length of the shadow of the gnomon was equal to the length of the gnomon, and accordingly the length of the shadow of the pyramid (measured from right beneath its top, hidden inside the pyramid) was equal to its height.

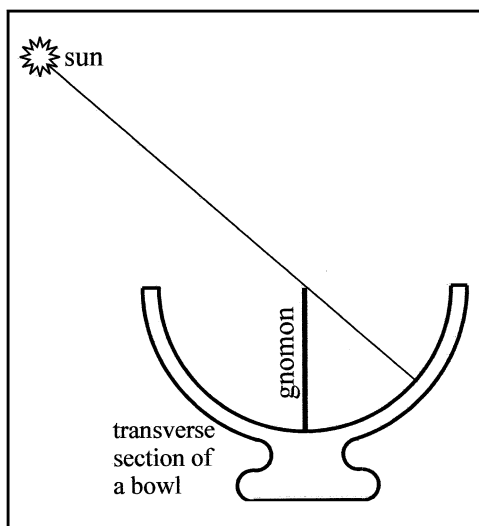
Let us return to Fig. 2.17. This picture invites us, as it were, to draw yet another line from the sun downward to the flat earth, and to measure the distance of the sun. To be able to do so we first need to calculate the distance from A to the point on earth where the sun is right above our head (in the zenith). How this problem can be solved, we will see in Chap. 16. Another possible application of the gnomon is to outline the shape and boundaries of the inhabited part of the earth (the οἰκουμένη) on a map of the flat earth, as will be discussed in Chap. 6 and is shown in Fig. 6.1.

A later development is to place the gnomon vertically in the center of a hemispherical bowl with its top in the plane of the bowl's rim. Such an instrument is called a σκαφῆ ("bowl"). The bowl creates an inverted celestial vault. The shadow of the gnomon's tip draws curves on the inner side of the bowl that mimic those of the sun in its daily track along the celestial vault (see Fig. 2.19). The oldest σκαφῆ dates to the fourth century B.C. (Pedersen and Pihl 1974: 47).

As we have seen, when you are walking with a stick it is not a very helpful to use it as a gnomon to tell the time of the day. Yet the gnomon can rather easily be used to make appointments, as a kind of portable agenda. Today, we are used to make appointments to the minute, checking our watches. For instance, we will meet at a

<sup>20</sup> According to Clayton 1994: 44, the norm was  $51^\circ 52'$ .

**Fig. 2.19** Transverse section of a bowl with an upright gnomon

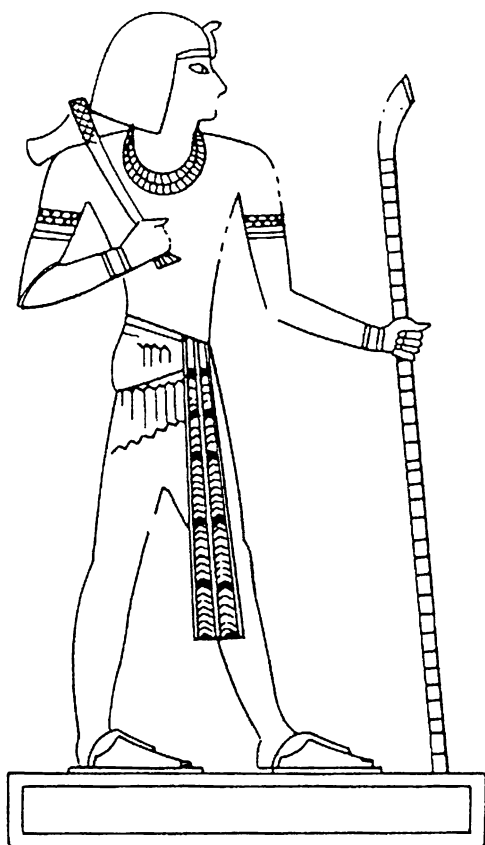


quarter past five in the afternoon; the train departs at 10.37 a.m. sharp, etc. The ancient civilizations, too, with the steadily increasing complexity of their societies, must have felt a growing need for an instrument that enabled people to make rather precise appointments. The ancients used the *clepsydra* to tell the hours, but this instrument was of course tied to one place and thus of no use for making appointments when the persons involved were at some distance from each other. Two (or more) staffs, used as gnomons, however, were well able to do the job. Mayall and Mayall hint at such a use of the gnomon for making appointments, when they write: “How could the traveler return at a prearranged time? He could carry with him a stick equal in length to the height of the one which had been securely placed in the ground near his cave. No doubt Mrs. Caveman frequently remarked, ‘don’t forget your shadow pole and return when the shadow’s length is one pole’” (1938: 2). However, the authors are too precise, for a serious advantage of the gnomon is that the two persons do not need to carry identical sticks (sticks of the same length). Any vertical stick will do when you arrange to make an appointment like that of Mr. And Mrs. Caveman. This is the only place in the literature that I could find where the possible use of gnomons for making appointments is mentioned.

This method could be easily generalized. Imagine two or more persons carrying sticks with standard marks of, say, one half, one quarter, and one-third of the stick, or even a finer scale. People could then make an appointment when the shadow of the stick was, for instance,  $1\frac{2}{3}$  its length. Of course, you will not only have to take into account that the same shadow length will occur twice a day, in the morning and afternoon, but also that the same shadow length will indicate different times of the day according to the season. For instance, in Athens in 500 B.C. around the 9th of March the shadow of a gnomon was equal to its length at noon, whereas 3 months

later (9th of June) it had the same length at 8.40 a.m. and at 3.20 p.m. (local time). This would not have caused a big problem, as a daily use of the gnomon would have led to a continuous adjustment of the length of the shadow to make an appointment for approximately the same desired time of the day. Provided all persons involved noticed the shadow length agreed upon, they would all come at about the same time for their appointment. There are some indications that the ancients did it this way. I do not know whether Greek staffs with measuring marks have been found, but some Egyptian staffs seem to bear such marks, as in the statue of Amenhotep II in Fig. 2.20 (Isler 1991b: 174, Fig. 23).

**Fig. 2.20** Statue of Amenhotep II holding a staff with a measuring scale on its shaft (Isler 1991b: 174, Fig. 23, by the courtesy of Martin Isler)



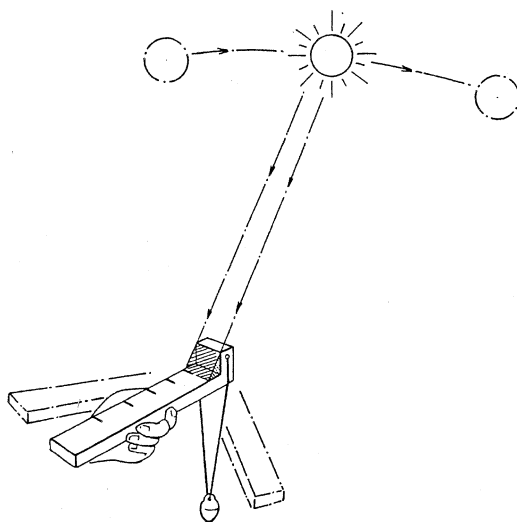
Roman indications of calculating with fractions of staff length are in Pliny: “In Egypt at noon on the day of the equinox the shadow of the gnomon measures a little more than half the gnomon itself, whereas in the city of Rome the shadow is one-ninth shorter than the gnomon, in the town of Ancona  $1/35$ th longer, and in the district of Italy called Venezia at the same time and hour the shadow is equal to the gnomon” (*Naturalis historia* I: 182, my translation). Similar remarks were made a century



earlier by Vitruvius (*De architectone* IX: 1.1). These observations regard the differences in shadow between different cities, but the point is that the shadow lengths were expressed in terms of parts of the length of the gnomon. As stated previously, the gnomon that is always available is the upright human body with its shadow. Isler remarks somewhere that “the empirical method of telling time by estimating, in paces, the length of a man’s own shadow, is ancient and widespread” (1991b: 179). An amusing example is in one of Aristophanes’ plays, when a hungry person concludes from the length (in feet) of his own shadow that it is time for dinner (*Ekklesiazusae* 652).<sup>21</sup> Of course, this last method is much less precise than measuring the length of the shadow of a well-scaled staff.

Concluding this section it may be clear that the gnomon, being by far the simplest tool you can think of, and although it was practically confined to use by daylight, was actually a powerful and multifunctional instrument. Moreover, the gnomon inspired the development of computation and measurement, and more specifically stimulated the calculation of angles. If the invention of the wheel stood at the cradle of technology, the use of the staff as a gnomon can be said to have stood at the cradle of the natural sciences. And if it is true that Anaximander introduced the gnomon in Greece, he may also be credited with the introduction of measurement and calculation as scientific tools.

The Egyptians used an instrument, called *merkhyt* (or *merkhet*) that is akin to the gnomon (see Figs. 2.21 and 2.23 right). The *merkhyt* is called after its upright part as a *pars pro toto*. Actually, you may look upon the *merkhyt* as a gnomon with a part of the ground attached to it (the horizontal plank). The *merkhyt* is a rather small instrument,



**Fig. 2.21** The handling of a *merkhyt* according to Isler (Isler 1991a: 67, Fig. 8, by the courtesy of Martin Isler)

<sup>21</sup> Similar remarks in Menander, fragment 304 (364K) and Eubulus, fragment 119.

which makes it easy to carry along. In modern representations (e.g., recently in North 2008: 31, Fig. 20), it is often depicted with a crossbar on top of its upright part, but this is a fiction resulting, as Isler has convincingly shown, from a wrong reading of an Egyptian text. Moreover, such a crossbar has never been found (See Isler 1991a: 57–59, 1991b: 177–179). A plumb on a line, as in Figs. 2.21 and 2.23, was used to keep the instrument horizontal. Isler lets the observer hold the *merkhyt* in his hand (Fig. 2.21 = Isler 1991a: 67, Fig. 8), but it seems more appropriate to put it on something like a wall or table. When it is turned toward the sun, the shadow of the short upright part, thrown on the horizontal piece, can be read on a scale.

In the description of a *merkhyt* found in the cenotaph of Seti I ( $\pm 1280$  B.C., see Fig. 2.22), the mark that is nearest to the upright part is obviously the noon mark at the equinox, as the angle of the shadow at the upright part is about  $30^\circ$ , corresponding to the latitude of northern Egypt. The plank is divided according to the numerical indications 3, 6, 9, and 12, given in the text (Fig. 2.22, columns 8 and 9). Nowhere is indicated which unit has to be taken 3, 6, 9, or 12 times. I take it that the counting unit is the distance between the upright part and the noon mark (which we may call “a”) and that the counting starts from the noon mark, although this is not well represented in the drawing. This results in a distance of  $3a$  between the noon mark and the second mark, a distance of  $6a$  between the noon mark and the third mark, and so on.<sup>22</sup>

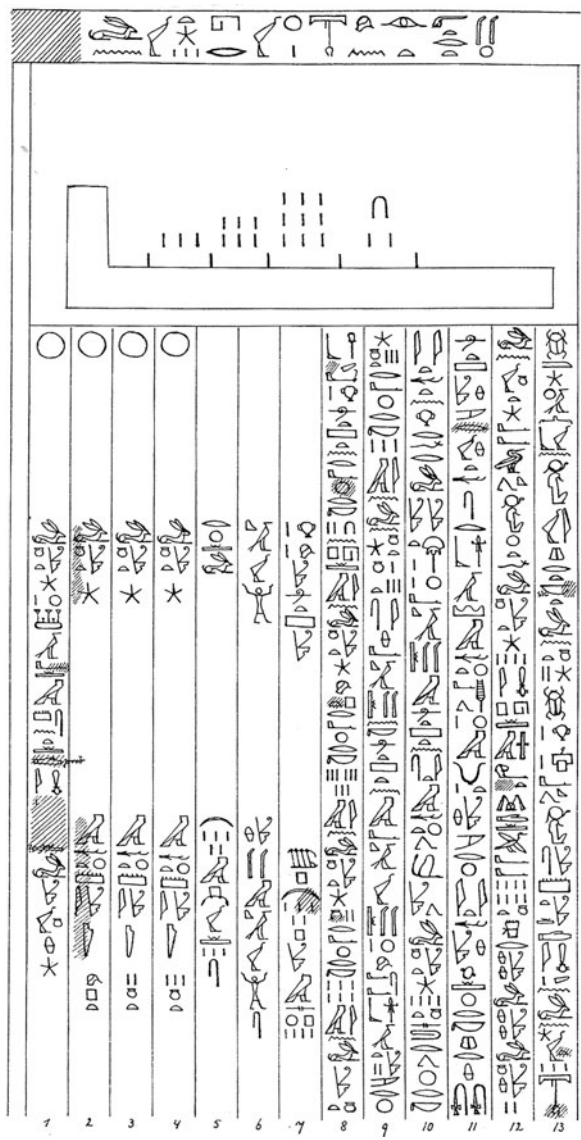
A similar counting method is used on the *merkhyt* that is preserved in the Ägyptisches Museum in Berlin (see picture in Von Bomhard 1999: 68–69, Abb. 49), although this one shows marks in a rising sequence (1:2:3:4:5). On this specimen the noon mark is so close to the upright part that the instrument must have been calibrated for the summer solstice. Henceforth, I confine myself to a discussion of the *merkhyt* in the cenotaph of Seti I, but, *mutatis mutandis*, the same holds for other *merkhyts* as well.

A main problem is that the way in which the marks are branded on the plank makes no sense as an indication of hours or other time units. The noon mark, for instance, is valid only on the days around the equinoxes. In other times of the year, the shadow at noon is either shorter or (much) longer. This entails that the marks in different seasons indicate different times of the day. Moreover, the equal distances between the marks do not correspond to equal time units. As Clagett puts it: “Even if these marks correctly measured equal hours at the equinoxes (which they did not), they would not have accurately marked the lengths of those hours at other times of the year in view of the changing declination of the sun throughout the year” (1995: 86).

Nevertheless, in the text, the marks are said to indicate the hours of the day. The word “hours,” then, is used here in a rather loose way. The instrument neglects the first two hours in the morning and the two last afternoon hours, as is explicitly mentioned in the text in columns 12 and 13: “It sums at [only] eight hours, for two hours have passed in the morning before the sun shines [on the shadow clock] and

<sup>22</sup> The text on top may be translated as “knowing the hours of day and night, starting from fixing noon”, as I will defend in a forthcoming article.

**Fig. 2.22** Description of a *merkhyt* from the cenotaph of Seti I (Frankfort 1933: Plate LXXXIII)



another two hours [will] pass after [which] the sun enters [the Duat]” (transl. Clagett 1995: 466).<sup>23</sup> Consequently, the mark that is farthest away from the upright part marks the end of the second hour in the morning (and of the fourth hour in the

<sup>23</sup> Strictly speaking this holds only for the time between the autumnal equinox and the vernal equinox, when the noon shadow falls either on the first mark (at the equinoxes) or somewhere in between the first and the second mark. In the other half of the year, the shadow falls somewhere between the upright part and the first mark, thus creating an extra “hour.”

afternoon), although in column 8 it is called (the mark of) the first hour. By this last expression is meant, accordingly: the first “hour” indicated on the instrument.

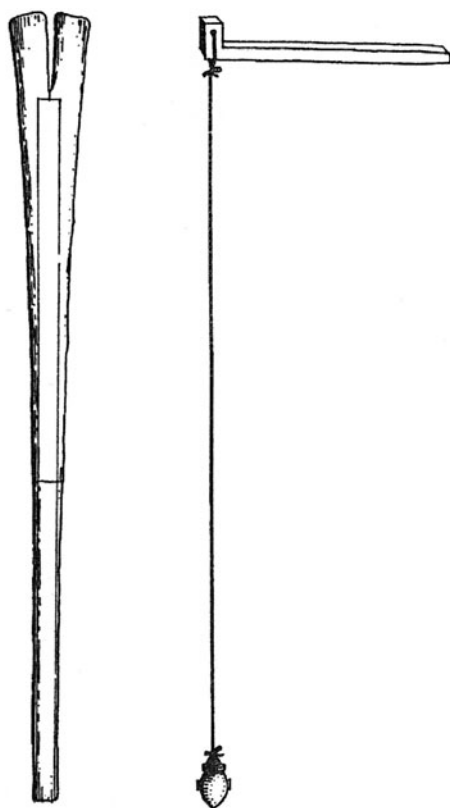
All this taken together results in the conclusion that the *merkhyt* has, to say it friendly, a very limited use as a time teller. The distances of the marks on the instrument are apparently not meant to indicate precise hours of the day, but chosen in a way that should make them easy to reproduce in order to get exact copies. This feature leads to an interpretation of the use of the *merkhyt* analogous to that given above for the gnomon: the instrument was perfectly apt to make appointments or to fix the moment of, say, a certain ceremony. As far as I can see, scholars have always tried to give an interpretation of the use of one *merkhyt* at a time, whereas nobody has bothered about the use of two or more identical *merkhyts*, used by different persons. When two or more persons had a copy of a *merkhyt*, made according to identical instructions, they could easily agree to meet when the shadow had reached, e.g., the second mark in the morning, or start a celebration when it had reached the fourth mark in the afternoon, and so on. No matter the season of the year, they would all come at the appointed place at the right time. As the marks do not indicate exact times of the day, it does not matter very much where exactly they are drawn, provided they are identical on the *merkhyts* of the persons who make the appointment. Summarizing, three features make the *merkhyt* into a rather practical instrument for making appointments: (1) that it was portable and thus easy to carry with you, (2) that the shadow could be read on the instrument itself instead of on the ground, and (3) that it was easy to reproduce, especially when its marks were at regular distances, so that more people could handle identical instruments. I do not discuss here later developments of this instrument with tilted hour scales, as this would take too much space.

In the literature, the *merkhyt* is often mentioned in combination with another instrument, called the *bay* (which is called *merkhyt* as well by some authors).<sup>24</sup> The *bay* and the *merkhyt* seem to belong together, as at least one set has been found with the name of the same priest on both instruments. The *bay* is a stick with a split upper end. The length of the *bay* in Fig. 2.23 is 52.5 cm. Perhaps it is noteworthy that the *merkhyt* was written as an ideogram in hieroglyphs (see Isler 1991a: 63), but that this is not the case with the *bay*. How this instrument was used is a much discussed question. Borchardt was the first to describe its supposed use, with the following words: “ein Visirstab, der vertical dicht vor das eine Auge zu halten ist, während man das andere schließt” (1899: 14, see also Borchardt 1920: 53–54). Other authors repeat this alleged use of the *bay*, suggesting that “it would concentrate the vision and so give a sharper image” (West 1982: 121). I am not able to understand, however, what the advantage would be of looking through the split end of a stick held before the eye.

As the *bay* and the *merkhyt* seem to belong together, several authors have tried to imagine what their combined use could have been. Sloley figured out that the observer and his aide were sitting on a north–south line, the first holding a *bay* in one hand and a *merkhyt* with a plumb line in the other, whereas the aide holds the plumb line of his *merkhyt* above his head (see Fig. 2.24). The observer is supposed

<sup>24</sup> E.g., Sloley (1931: 169 and Plate XVI, 4).

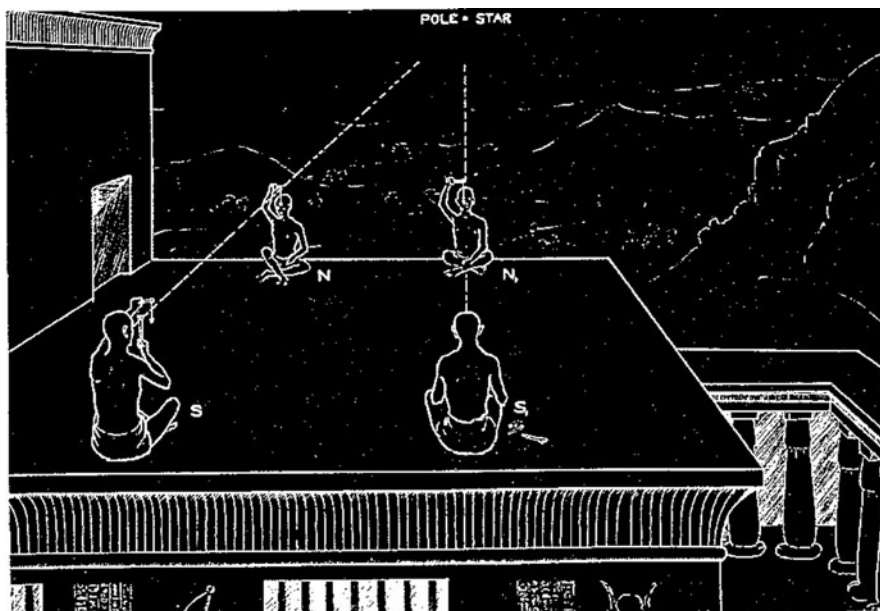
**Fig. 2.23** Two Egyptian instruments, a *bay* (left), and a *merkhyt* with plumb line (Borchardt 1899: 10)



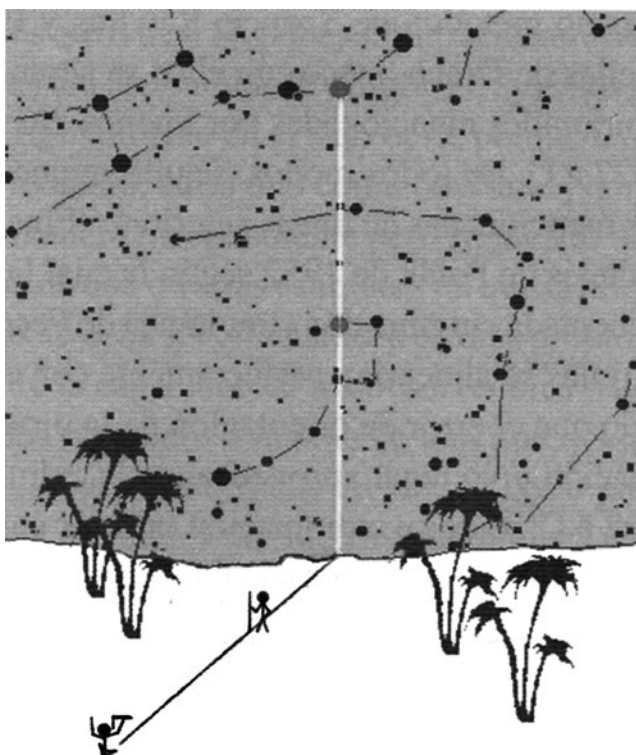
to look through the split end of the *bay* and along the plumb line of his *merkhyt* and that of his aide to mark the position of a star.

Other attempts to comprehend the combined use of the *bay* and the *merkhyt* are derivatives of Sloley's picture but usually have only one *bay* and one *merkhyt*. Mostly, they have one observer hold the *bay* before him, while an aide holds the *merkhyt* in his hand. (e.g., Ronan 1971: 56). The observer is supposed to look through the split end of the *bay* and along the plumb line of the *merkhyt* to mark the position of a star. Lull inverts the order and lets the observer look along the plumb line of the *merkhyt*, whereas the aide holds a kind of stick (2006: 296, Fig. 98, and 299, Fig. 100, here reproduced as Fig. 2.25).

The trouble with all these alleged methods is that even if the supposed observers could manage to hold their hands still enough to make any observation possible, this looks like a clumsy way of observing a star. Neugebauer and Parker already remark: "That two persons, sitting opposite each other, cannot resume exactly the same position night after night is clear. To fix accurately the moment of transit, when even very small motions of the eye of the observer will displace the apparent position of a star, is impossible" (1960–1969, Vol. II: x). Probably for this reason,



**Fig. 2.24** The use of *merkhyt* and *bay* according to Soley (1931, plate XVII,1 between 170 and 171)



**Fig. 2.25** The use of *merkhyt* and stick according to Lull (2006: 299, fig. 100)



Pecker makes the *merkhyt* the cross-beam of a gallows, on which a plumb line hangs (2001: 31, Fig. 1.13). The observer is thought to stand behind a board with a vertical slit that is provided with a scale, and to look through this slit along the plumb line to determine the apparent height of a star above the horizon. Needless to say that such a board with a slit and a scale is no more than a product of Pecker's fantasy.<sup>25</sup> None of the proposed methods of using the *bay* seems to me convincing.

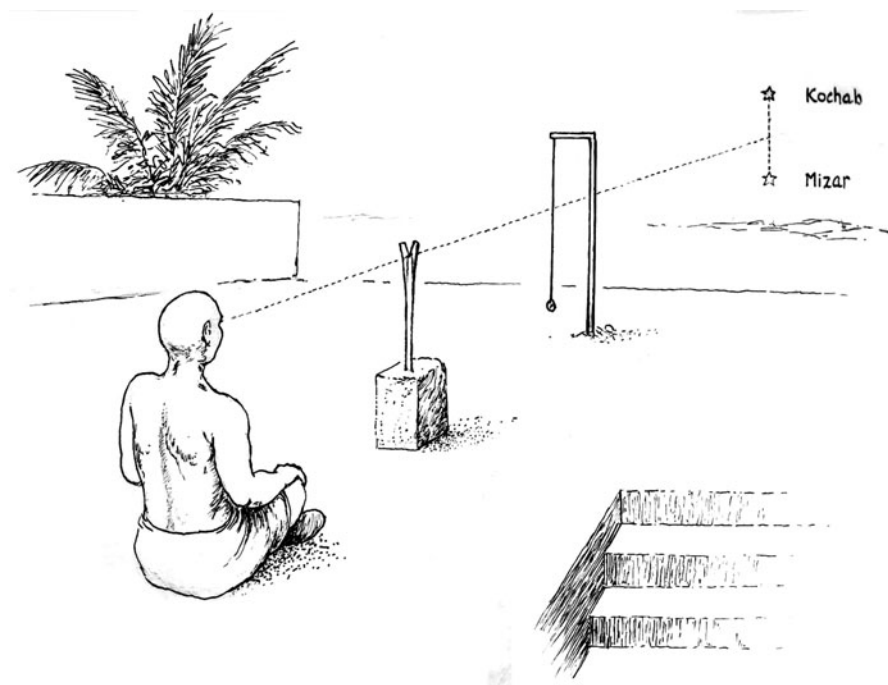
Of course the *merkhyt* itself is not necessary for the use of its plumb line as a kind of sighting instrument. A mere *plumb line*, its upper end tied to something like the gallows mentioned above, will do the job as well. It is well known that the ancient Egyptians were interested in the culmination of other stars, especially the 36 so-called decans.<sup>26</sup> To watch these culminations, the observer needed a permanent and dependable north–south line. I think he could obtain such a line by using the *bay* as a calibration device. The procedure would look like this: The observer sets himself south of a rather long plumb line that hangs down from a stake and, always looking with one eye to prevent parallax problems, he waits until he can move so that he can see stars culminate when passing the plumb line. Then, he lets his aide put a *bay*, with the split end on top, perpendicularly in a holder between himself and the plumb line, so that he sees the plumb line exactly in the split of the *bay*. As soon as he has achieved this, he asks his aide to fix the holder on that spot. Now, he has made sure that every time he will return to the same place and put his *bay* into the holder, he will provide a perfect north–south line by setting himself south of the *bay* so that the plumb line is caught in the split of the *bay*. In other words, he has made a simple but convenient observatory, by means of which he can observe the culmination of a star, say Sirius, or another of the 36 so-called *decans*. Mark that the *bay* is not held close to the eye, as Borchardt supposed, but at a certain distance, because the observer uses the *bay* only to make sure that he will sit in the right place. The observatory is shown in Fig. 2.26. This reconstruction of the way the instruments were used is of course also a fruit of fantasy, but at least it makes sense.

The procedure just described can be used for stars on the northern sky. For the observation of culminations in the southern sky, the observer, having drawn a north–south line on the ground, simply has to change his position to north of the plumb line and to look southward, making sure that the plumb line is seen in the split of the *bay*. In Fig. 2.26 I made use of the fact, exposed by Spence, that in 2467 B.C. the imaginary line between two stars, Mizar ( $\zeta$  of the Big Dipper) and Kochab ( $\beta$  of the Little Dipper), ran through the pole (2000: 320–324). Lull did the

<sup>25</sup> Isler proposes still another use, quite different, of the *bay*. He lets the observer put it upside down (with the split end under) at the top of the shadow of a gnomon “to help clarify a shadow by reducing surface reflection” (1991b: 162, Fig. 9; cf. 1989: 198, Fig. 5; see also Lull 2006: 292, Fig. 96). Moreover, Isler shows all kinds of forked and curved sticks that could function as a gnomon, but none of them looks exactly like the *bay* in Fig. 2.23.

<sup>26</sup> The so-called decans were stars that were used by the ancient Egyptians for marking the hours of the night. More on this subject in Von Bomhard (1999: 50–65), and especially in Leitz (1995).

same in Fig. 2.25 above. According to Spence, this datum was used to align the pyramids. Spence concluded that, with an uncertainty of 5 years, the pyramid of Cheops must have been built in 2467 B.C. Spence's article has met with severe criticisms that need not bother us here.<sup>27</sup> As already said, any culminating star could have been used to set up the observatory as in Fig. 2.26.



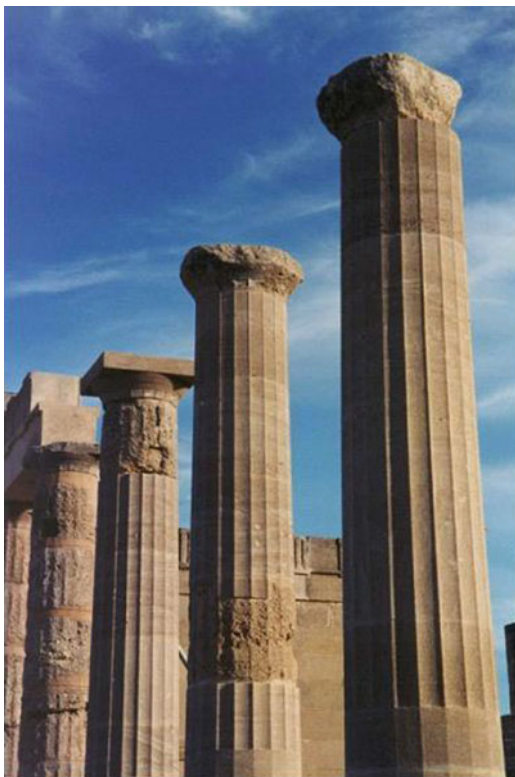
**Fig. 2.26** An Egyptian observatory with *bay* and plumb line (2467 B.C.) (drawing by Hans Exterkate)

At the end of this chapter on archaic astronomical instruments, we may mention Kauffmann's suggestion that the play of the moving shadows on the cannelures of temple columns functioned as a sundial (1976: 28). There are, however, no ancient sources to confirm this hypothesis (Fig. 2.27).<sup>28</sup>

<sup>27</sup> See e.g., the discussion in Gingerich (2000: 297–298), Rawlins and Pickering (2001: 699), Spence (2001: 699–700), Bauval (2001: 320–324), and Lull (2006: 299–300).

<sup>28</sup> See for some critical remarks Couprie and Pott (2001: 47).

**Fig. 2.27** The play of light and shadow on the cannelures of temple columns (photograph by Victor Abrash)



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