Nighttime and Easter Time

The Rotations of the Sun, the Moon, and the Little Bear in Renaissance Time Reckoning

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1. *The Resurrection of 1461, with a Table to Find Easter. Italian (Florence), 1461. Engraving, 14¼ x 7½ inches. Copyright Trustees of the British Museum*

To know the time – the time of the year, the time of the day, the time of the night – has been of concern to man since his earliest history. For modern man the telling of time is marked by calendar and clock. These devices tend to obscure the relationship between the measurement of time and the motion of the celestial bodies upon which these measurements depend. Sixteenth- and seventeenth-century men, however, told time with instruments that made direct use of the motion of the sun, the moon, and the stars to fix the dates of important days in the year, such as Easter, and to find the hour of the day or night.

Easter is the most significant feast of the Christian liturgical year, for it is the celebration of the Resurrection of Christ, and the day upon which all the movable feasts of the Church depend. With the exhortation *Uno die et uno tempore per omnem orbem* ("On the same day and at the same time throughout the world") the Council of Arles in 314 sought to unify the celebration of this holy day in the Christian church. In 324 the Council of Nicaea finally defined Easter as the first Sunday after the first full moon after the vernal equinox. A difficulty arose, however, in trying to find the day of Easter in a calendar, the Julian, which depends, as does our modern Gregorian calendar, on the motion of the sun. Because the sun and the moon have different cycles, the date of Easter in the calendar changes from year to year. (A detailed explanation of how the date of Easter was determined is given in the Astronomical Explanations.) The elaborate table shown in Figure 1 (well known because it is the earliest dated Italian print) provides a succinct illustration of Easter's yearly variation. The outer two circles give the date of Easter and the inner two the first Sunday in Lent from 1429 to 1476. F stands for February, M for March, and A for April. Consecutive years do not appear next to each other but in every thirteenth wedge. Easter and Lent for 1461 are in the wedge to the right of the cross at the top of the print, the first occurrence of A 5 and F 15. Thirteen wedges counterclockwise will give the feasts as A 13 and F 24 for the year 1460; thirteen wedges clockwise will give the dates A 18 and F 28 for 1462. The BS around the circumference of the circle indicate leap years.

Several unusual instruments in the Metropolitan Museum's Tucker Collection illustrate how information such as that needed for the table in Figure 1 was obtained during

A TROVARE · LAPASQVA · PERSEMPRE · SECONDO · CHELLA · VERRA · ANNO · PE
RAN O · ET · CONTA · INQVESTO · MODO · CELLANNO · 1461 · FIA · LAPASQVA · ADI
V · DAPRILE · COME · VEDRETE · DISOPRA · APIE · + · ET · POI · ANNOVERATE · PELAL
TRO · ANNO · LASCIANDO · LACHASELLA · DOVE · ISTATO · QVELANNO · INSINO · A · 13 · E
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LACHASELLA DOVE ISTATA QVELO ANNO DAMANO DIRITTA · ET · GVARDATE · IN
QVELLA · CHASELLA · ET · VEDRETE · AQVNTI · DI · ELA · DOMENICA · I · NAZI · ALCARNEVA
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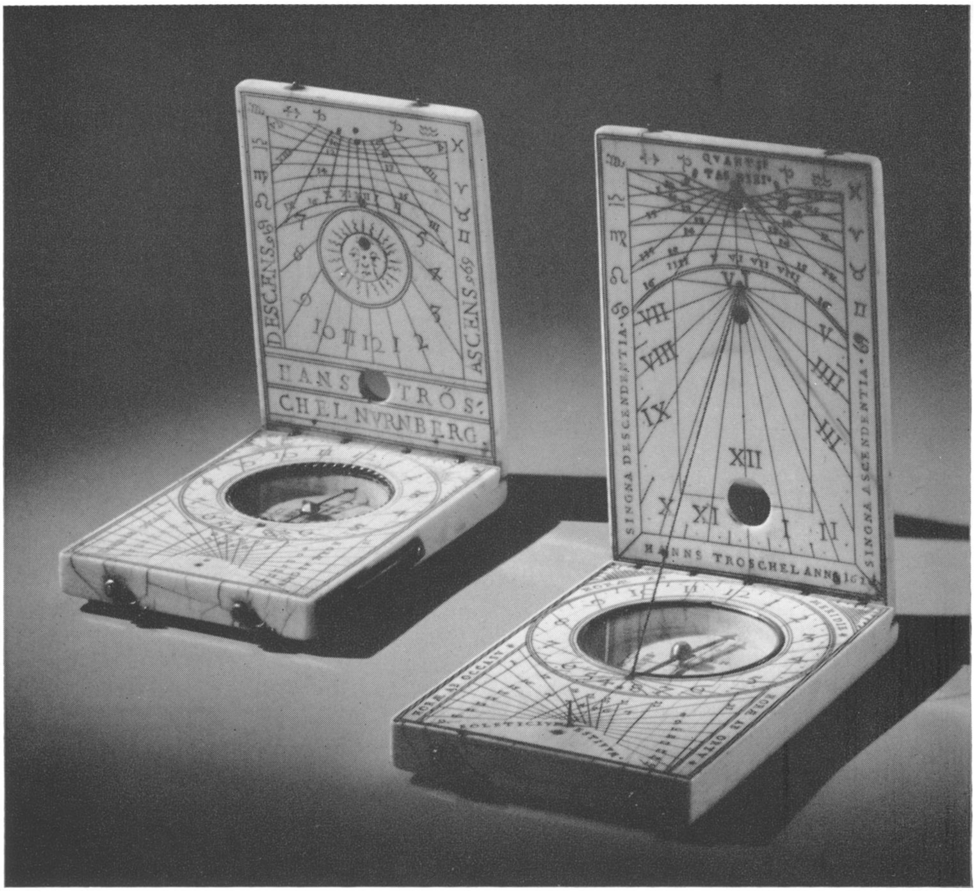


2. *Two portable diptych sundials, calibrated in the same manner, for use around the latitude of Nuremberg. The dial on the left, which is missing its style and gnomons, is stamped* HANS TRÖS=/CHEL NVRNBERG; *it was made by Hans Troschel the Elder (working 1578-1612). German (Nuremberg), about 1598. Ivory, 3½ x 2⅜ inches. Gift of Mrs. Stephen D. Tucker, 03.21.38. The dial on the right, stamped* HANNS TROSCHEL ANNO 1620, *was made by Hans Troschel the Younger (working about 1616-1631). German (Nuremberg), 1620. Ivory, 3⅞ x 2⅝ inches. Gift of Mrs. Stephen D. Tucker, 03.21.53*

the Renaissance. The date of Easter could be calculated with the aid of two multipurpose diptych dials shown in Figure 2. Typical products of early seventeenth-century Nuremberg, both instruments are inscribed on the bottom with sets of numbers (Figures 3 and 4). The nineteen numbers that are found in the outer two circles of each dial give the number of days past the new moon on the first day of January in consecutive years of a nineteen-year cycle: the outer circle for the Julian calendar, and the inner for the Gregorian. Called epacts, these numbers, with a few calculations described in almanacs and popular treatises of the period, yield the date of the first full moon after the vernal equinox and thus the date of Easter. In fact the calculations give the number of days past the new moon on any day of the year.

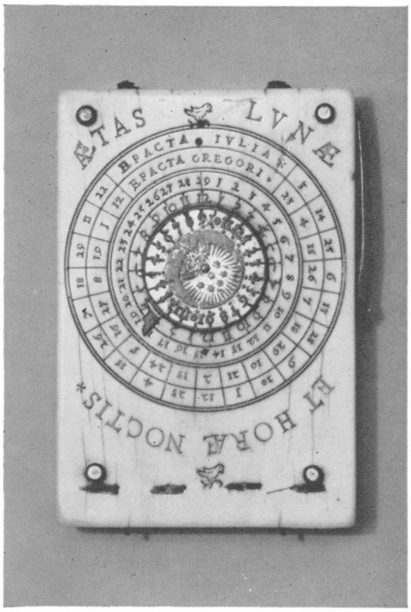
More mundane applications of the epact numbers range from predicting the nights that would be illuminated by the moon to determining the ebbing and flowing of the tides. As Thomas Blundeville, an Elizabethan essayist on astronomical and navigational instruments, declared in his *New and Necessarie Treatise of Navigation* (London, 1594), "you must know the course of the Moone whereon dependeth the knowledge of the tydes in all places."

The epact numbers are even helpful in dating the instruments themselves. The little bird on the bottom leaf of the dial on the left in Figure 2 (shown in Figure 3) is the maker's mark of Hans Troschel the Elder, who worked in Nuremberg from 1578 until his death in 1612. Because the first epact numbers are three for the Julian calendar and twenty-three for the Gregorian calendar and because the epact numbers repeat themselves every nineteen years, the instrument must have been made around 1598, the only year with the epact numbers three and twenty-three during the working life of the maker (see Astronomical Explanations).

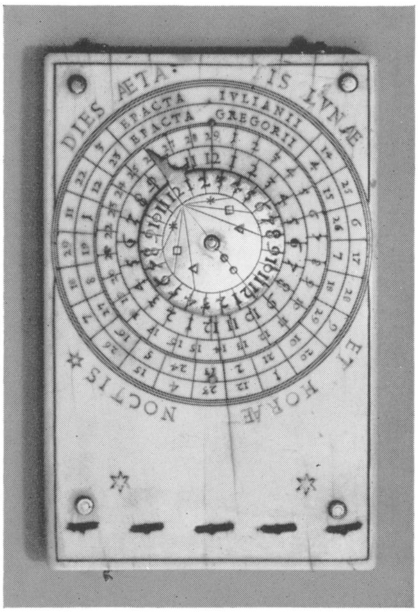
The second instrument (Figure 4) was made by Hans Troschel's son, and it is dated 1620. The epact numbers on this instrument, fourteen for the Julian calendar and four for the Gregorian, begin in the year 1618. It is clear that the first pair of epact numbers does not necessarily fix the precise date of the instrument's manufacture, but it does give an approximation.

The two instruments can also be used to find the hour of the day or night. Various kinds of sundials are laid out on the interior of each ivory leaf (Figure 2). The sundial gives the time of day by recording the movement of the shadow cast by a string or style in the sunlight. At night the dial records the shadow cast by the string in the moonlight. This shadow, however, does not immediately indicate the hour of the night. The dials were laid out to record the sun's apparent course across the sky, which is quite a bit different from that of the moon (see Astronomical Explanations). To convert the sundial hours to night hours, a rotating brass disk of the volvelle on the bottom side of the lower leaf (Figures 3, 4) is used. When the pointer is set at the number of days that have elapsed since the appearance of the new moon (1 to 29), the hour of the night appears on the innermost ivory ring opposite the sundial hour on the brass disk. In Figure 2, the sundial on the right reads about 3:20 P.M.; if this were a nighttime reading taken when the moon was twenty-six days old (indicated by the brass pointer in Figure 4), the hour of the night would be 1:00 A.M. (as shown on the ivory ring), assuming there was enough moonlight to cast a shadow on the dial at all. The moondial could be used only during the part of the month when the moon was shining, which is not the case on the twenty-sixth day of the cycle. It was really very inefficient.

For purposes of reckoning time, the apparent motion of the stars is more precise than the motion of the moon. The stars have been used to tell the nighttime hours since ancient times. The *Kalendrier des Bergers*, a book that went through many editions from the fifteenth to the seventeenth century, sets forth a traditional method for memorizing the position of the constellation Ursa Major,



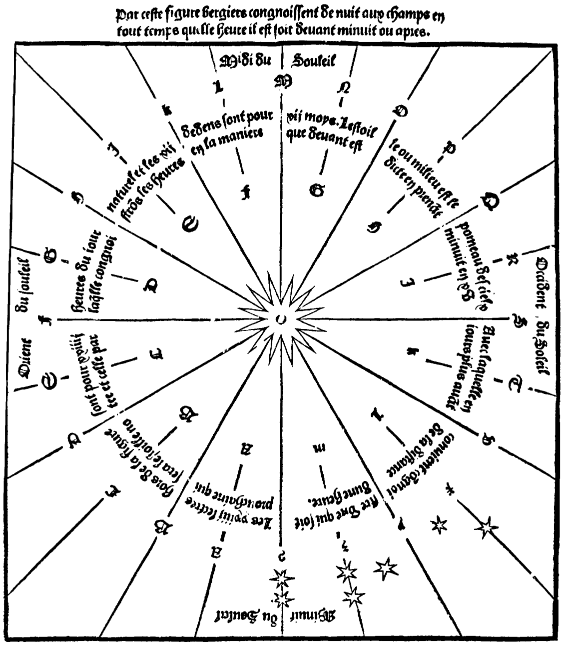
3. Reverse of the lower leaf of the sundial at the left of Figure 2. It is stamped AETAS LVNAE ET HORAE NOCTIS *(The age of the moon and night hours),* EPACTA IVLIA *and* EPACTA GREGORI, *and twice with the elder Troschel's maker's mark, a bird on a twig. The brass pointer here indicates the age of the moon, the number of days past the new moon, on Easter day in 1598*



4. Reverse of the lower leaf of the sundial at the right of Figure 2. It is stamped DIES AETA/TIS LUNAE ET HORAE NOCTIS *(The days of the age of the moon and night hours),* EPACTA IVLIANII *and* EPACTA GREGORII, *and twice with a six-pointed star, the maker's mark of the younger Hans Troschel. The inner two circles and the brass disk are used to calculate the night hours*

5. *Schematic diagram illustrating the position of Ursa Major with respect to the North Star. From Kalendrier des Bergers, Guy Marchant edition (Paris, 1500), folio l, p. v verso. Woodcut, 10⅝ x 7¼ inches. The New York Public Library, Astor, Lenox and Tilden Foundations, Spencer Collection*

6. *A shepherd aligning two ropes with the North Star. From Kalendrier des Bergers, Guy Marchant edition (Paris, 1500), folio l, p. vi recto. Woodcut, 5⅞ x 2¾ inches. The New York Public Library, Astor, Lenox and Tilden Foundations, Spencer Collection*



the Great Bear or Big Dipper, in the sky at midnight for each night of the year. The legend at the top of the schematic diagram in Figure 5 says, "By this figure shepherds in the fields at night can know at all times what hour it is, whether before midnight or after." The diagram illustrates the position of Ursa Major, the seven stars at the bottom, with respect to the North Star, Polaris (o), at midnight twice a month throughout the year. By memorizing the information contained in the diagram, the shepherd could estimate the hour of the night without using an instrument by observing the difference between the actual place of the constellation and the place it should occupy at midnight. To help him determine the position of Ursa Major with respect to Polaris at a certain time of the year, he could use the rope device in Figure 6. The *Kalendrier des Bergers* explains how to align the stars with this contrivance.

An instrument called a nocturnal accomplishes this time reckoning by the stars automatically. Descriptions of nocturnals abound in dialing books and navigational treatises of the sixteenth and early seventeenth centuries, when the instrument had its greatest vogue. No ship's complement was complete without a nocturnal "to know the hour of the night," according to Blundeville. Nocturnals continued to be made in the eighteenth century and were not unknown in the nineteenth.

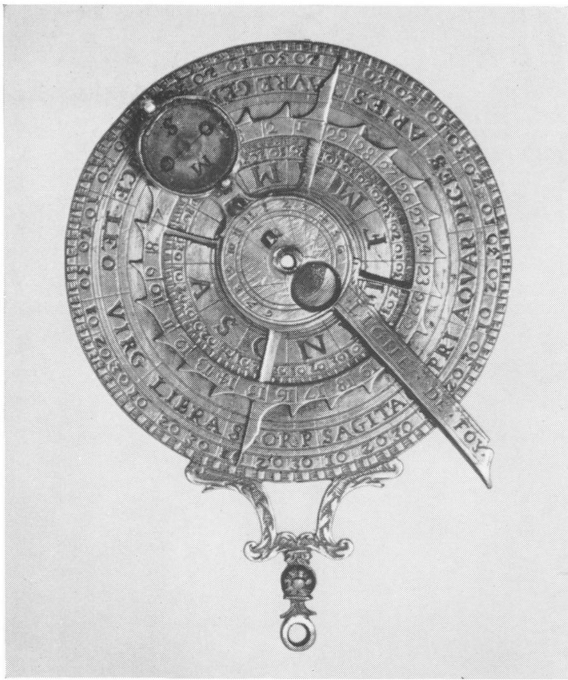
The earliest instrument in the Tucker Collection is a sixteenth-century nocturnal and sundial (Figures 7 and 8). There are two sundials on the instrument. One, on the face of the nocturnal, is a horizontal dial (its style now missing) together with a compass for orientation. The compass is marked s (Septentrion), o (Orient), m (Midi), and o (Occident) for North, East, South, and West. The compass needle is lost. The sundial on the reverse (Figure 8) is used by placing the gnomon standing vertically on the arm marked PIGN[ON] on the appropriate date of the year on the left side of the instrument and reading off the hour at the point where the shadow is cast on the right side.

The nocturnal consists of three separate and concentric disks, fastened together at the center. The largest is calibrated from the center to the outer rim to show the months of the year, the days of the month, the signs of the zodiac, and the degrees of the zodiac. On the outer rim is a handle.

The middle disk has twenty-four teeth to represent the hours. (The numbers 1 through 29 inscribed on this disk are not used for telling time at night, but have another function described below.) The smallest disk has a long pointer *(ligne de foy)* extending beyond the body of the instrument. In the center is a hole.

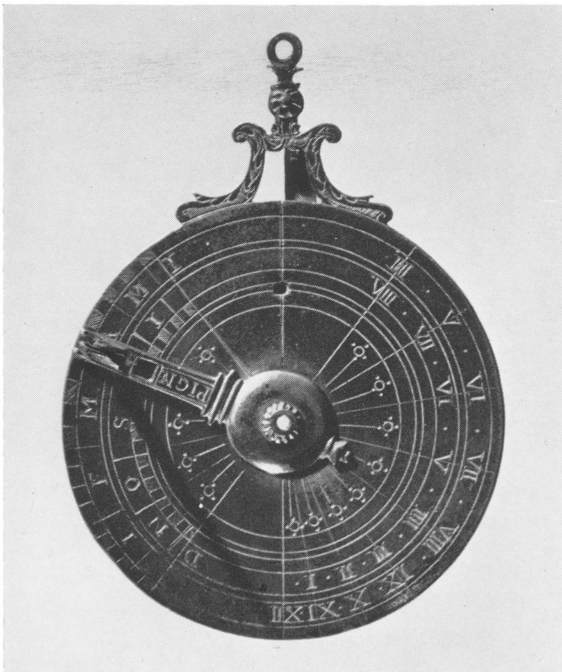
To find the time at night, either pointer on the middle ring is set for the day of the month (in Figure 7, April 12 or October 25). The instrument is held up by the handle until the North Star or Polaris, the star at the end of the tail of the constellation Ursa Minor, the Little Bear or, as it is now more commonly known, the Little Dipper (Figure 9), appears in the central hole. Next, the straight edge (ligne de foy) is rotated to align with the brightest star of the same constellation, the one nearest the head of the Little Bear. The hour may then be found by counting by sight or by touch the number of teeth between the pointer on the middle disk and the straight edge. The pointer on the date for which the reading is being taken denotes midnight. Counting clockwise from the pointer gives the number of hours past midnight, and counting counterclockwise gives the number of hours before midnight. In Figure 7 the instrument reads 8:00 P.M. on October 25. In Figure 11, the man is using Polaris and two stars from another constellation (see Astronomical Explanations).

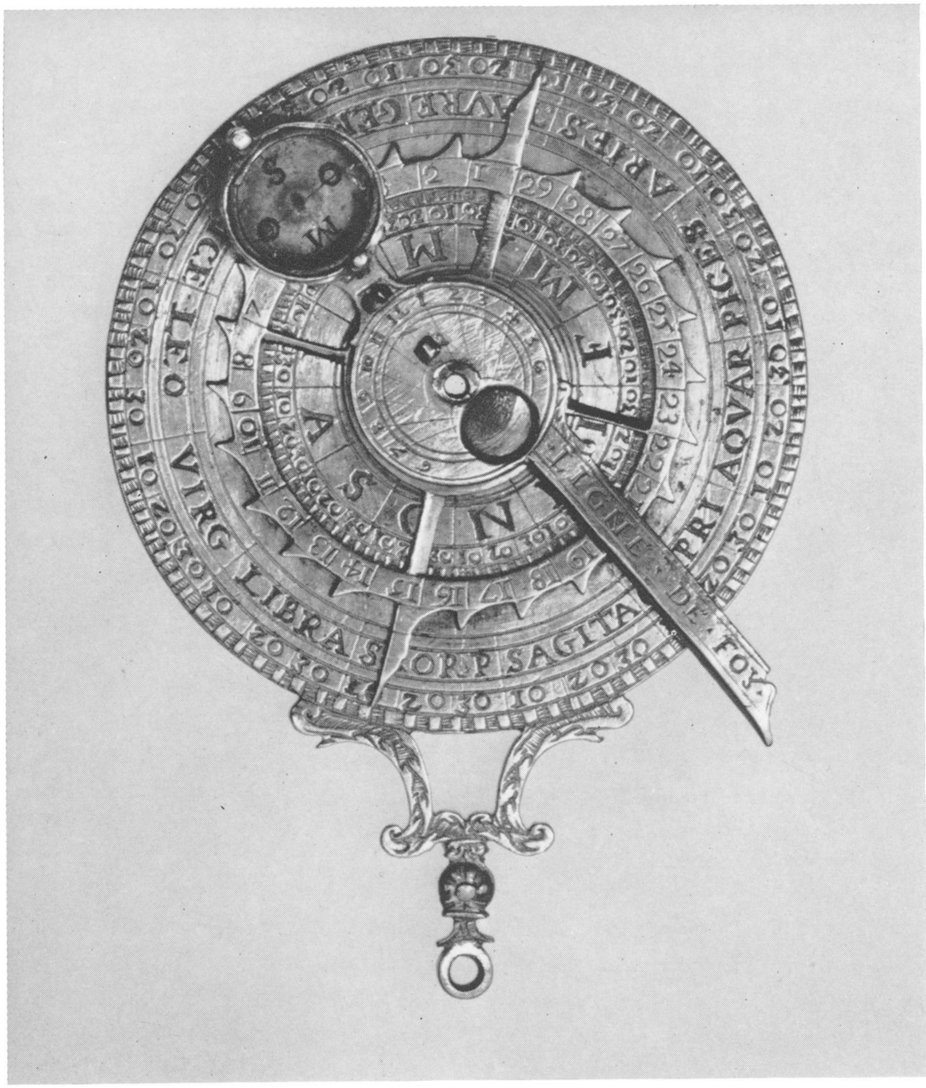
The Museum's nocturnal also has a device for finding the moon's phase and position in the zodiac (see Astronomical Explanations). In the words of the 1596 English edition of Martin Cortes's *Arte de Navegar* (see Figures 7 and 12), "To finde the place of the Moone we must holde the Index of the rundel of the Sunne [the pointer marked 1 on the middle disk of the nocturnal] fast upon that day of the moneth in which we desire to knowe the place of the Moone. And accompting in the rundel of the Sunne [the middle disk], the dayes that have passed from the day of the conjunction [the number of days after the new



7. Nocturnal and sundial. French, about 1550-1582. Water-gilt brass, with traces of blue and red enamel, diameter 2¼ inches. Gift of Mrs. Stephen D. Tucker, 03.21.69

8. Sundial on the reverse of the nocturnal in Figure 7





10. The nocturnal shown in Figure 7

moon, called the age of the moon] and where endeth that number of the dayes, if there we apply the index of the Moone [ligne de foy] it shall shewe in the circle of the signes, the place where she is. And so shall she appeare in the instrument [the off-center hole on the small disk] lightened, or darkened, more or lesse as in heaven."

If the new moon is on April 12, indicated by the upper pointer on the middle disk, and the age of the moon is nineteen, indicated by the ligne de foy, the moon will be found in two degrees of Capricorn. At the same time, its phase will be seen in the off-center hole in the top disk of the nocturnal.

The workmanship and the inscription on the nocturnal indicate that it was made in France not much earlier than the middle of the sixteenth century. Because the relationship of the days of the month to the signs of the zodiac is that of the Julian calendar, the instrument was probably made by 1582, the date when the Gregorian calendar was adopted in France.

A clear picture of the three essential parts of a nocturnal can be found in the illustrations of the sixteenth-century French *Recueil d'Horlogiographie* by Jean Bullant (Figure 13). They show the three parts of a nocturnal separately and joined together ready for use. The day of the year is given in terms of the position of the sun in the zodiac. The middle ring, unlike the middle ring of the Museum's nocturnal, has the hours of the night inscribed on each tooth because the Bullant nocturnal has only one purpose, to tell time at night.

While the sundial is still in use today, however little we may depend on it, the nocturnal, which gives the night hours by measuring the apparent motions of certain stars, is all but forgotten. With the use of a telescope, the astronomer still tells time from the motion of the stars. In fact, until the invention of the atomic clock, the stars remained the most accurate timekeepers.

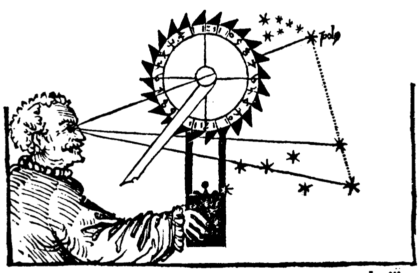
9. Representation of the constellation Ursa Minor, the Little Bear. From Oronce Finé's De Solaribus Horologiis (Paris, Guillaume Cavellat, 1560), p. 85. The apparent rotation of the star marked B *around the North Star, marked* A, *in the constellation is measured by the nocturnal in Figure 7. Woodcut, 1⅝ x 2½ inches. The New York Public Library, Rare Book Division*

Instrumentum syderale.

¶ Qualiter ex stellarum fixarũ motu nocturno tempore horę venãde sint paucis absoluã. Fiat primum rotula parua cum manubrio in simi litudine rotulę sequentis: quam diuide in vigintiquattuor horarum spa cia. His perfectis aptabis regulam seu Indicem in longitudine tanta: vt a centro rotulę vltra limbum protendatur. Hanc itaq3 regulam pone super centrum rotulę: et fac vtrum foramen rotundum in qd mittatur cla uus cum foramine rotundo qui ambo constringit: Ita vt index hac atq3 illac volui possit.

Vt Euidentissime Patet
In Figura Sequenti.

Ecce Figuram.



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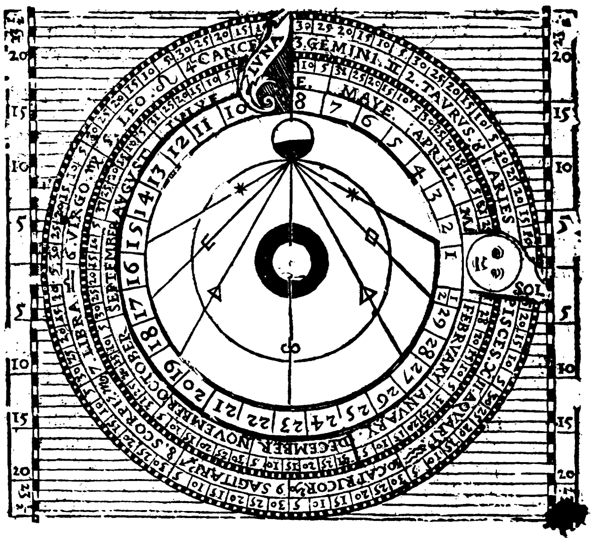
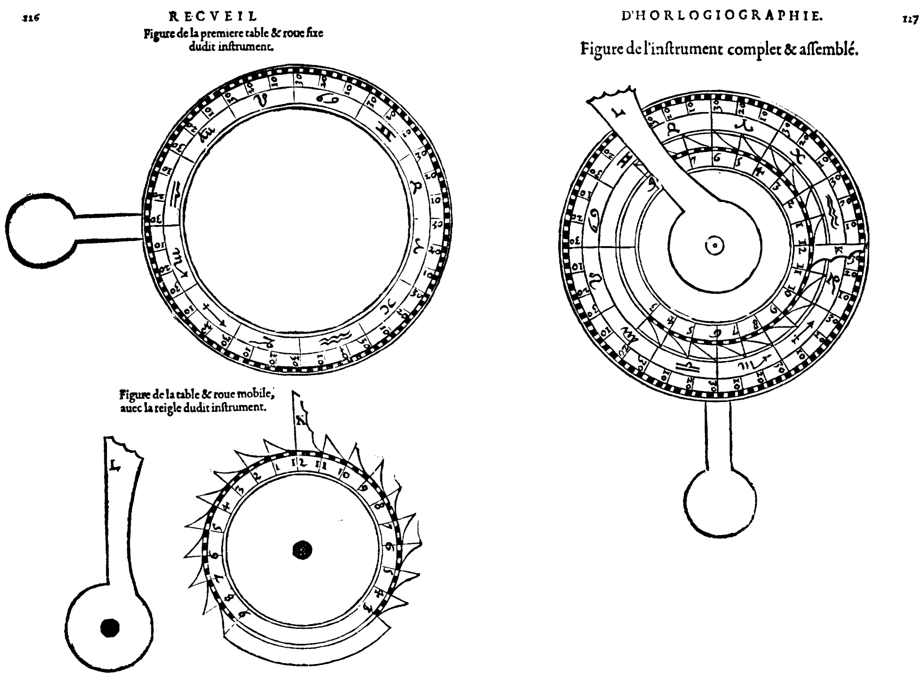
LEFT:

11. An illustration of the use of the nocturnal for sighting the North Star and the Guards of the constellation Ursa Major or the Great Bear. From the first edition of Petrus Apianus's Cosmographicus Liber (Landshut, 1524), sig. III recto. Woodcut, 4⅛ x 2½ inches. The New York Public Library, Rare Book Division



ABOVE:

12. An instrument "by which is found the place and declination of the Sunne with the dayes and place of the Moone." From Martin Cortes's The Arte of Navigation, translated into English by Richard Eden (London, Richard Watkins, 1596), folio 29 recto. Woodcut, 4½ x 4 inches. The New York Public Library, Rare Book Division



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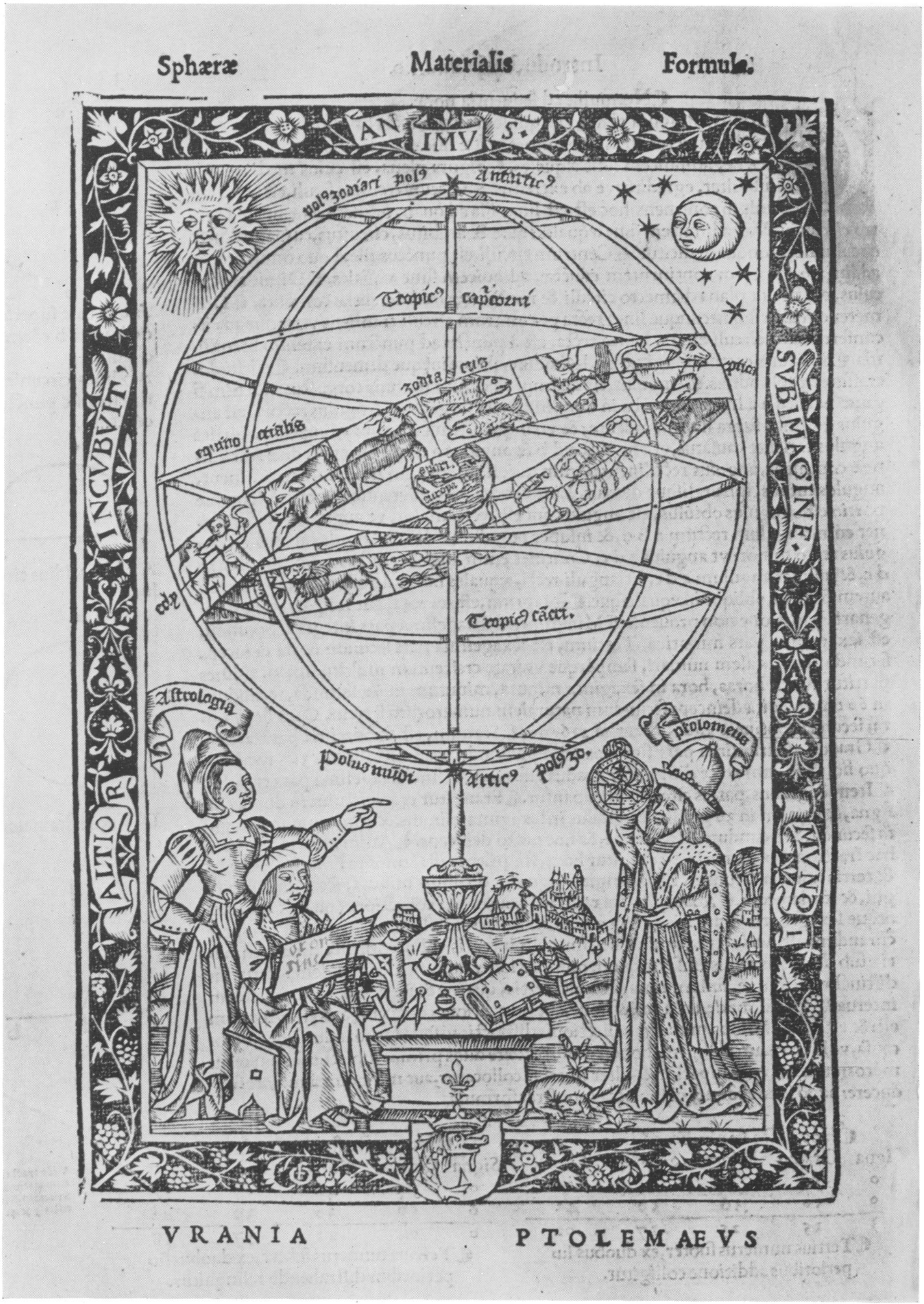
13. The components of a nocturnal. From Jean Bullant's Recueil d'Horlogiographie (Paris, Jean Bridier, 1561), pp. 126-127. Woodcuts, each 9½ x 6½ inches. Harris Brisbane Dick Fund, 28.46.2

Astronomical Explanations



14. Armillary sphere. From Johannus de Sacrobosco's Textus de Sphaera (Paris, Simon de Colines, 1538), p. 3 verso. This print is the work of Oronce Finé, mathematician and author of the Solaribus Horologiis from which the illustration of Ursa Minor in Figure 9 was taken. Woodcut, 7½ x 5 inches. Harris Brisbane Dick Fund, 34.99

The Date of Easter

The Council of Arles did not succeed in unifying the Church's celebration of Easter. There were two questions to be settled in order that Easter might fall on the same day throughout the world. The first, the theological problem, was one of definition, and the second, the astronomical one, was to reconcile the motions of the moon and the sun to the calendar.

The theological problem consisted in the main of a dispute between two factions. The Quartodecimans, who celebrated Easter on the fourteenth day of the new moon of the first month, actually the day of Passover as given in the Old Testament (Exodus XII:18 and Numbers XXVIII:17), were overruled by those who insisted that because the Resurrection took place on Sunday, Easter should fall on Sunday. The Council of Nicaea, called by the Emperor Constantine in 324, decreed that Easter should be the first Sunday after the first full moon after the vernal equinox. Easter would always fall on a Sunday, but never on Passover, for as Constantine explained in a letter to the bishops supporting the edict, Christians never "should follow the custom of the Jews in the celebration of the most holy solemnity."

Although the Council of Nicaea settled the theological dispute, the astronomical problems resulting from this definition of the day of Easter were far from settled. The understanding of these problems requires some knowledge of the motions of the moon and sun in relation to the earth.

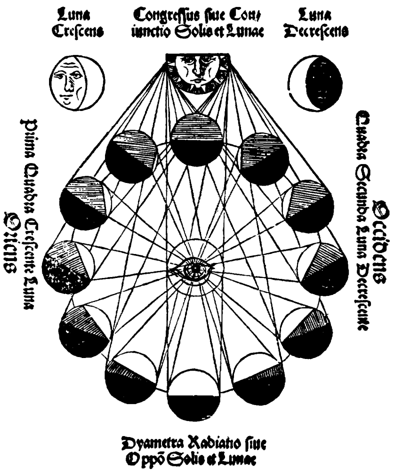
A simple picture of the world, according to the Ptolemaic system that was in use when the Metropolitan Museum's instruments were made, can be seen in Figure 14. The earth is a sphere at the center of a larger sphere of fixed stars. The south pole is at the top of the picture and the north pole at the bottom. The sun and the moon travel in an earth-centered orbit between the sphere of the earth and the sphere of the fixed stars. As seen from the earth, they seem to rotate through a circle of fixed stars called the circle of the zodiac (*zodiacus* in Figure 14). The zodiac circle is tilted at a 23½-degree angle to the earth's equatorial plane *(equinoctalis)* and is divided into twelve equal parts, each named for the constellation of stars within its boundaries. These are the twelve signs of the zodiac. The apparent motion of the sun and the moon through the zodiac would be from Aries, the Ram, at the vernal equinox, to Gemini, the Twins, on the far left, through the back half of the circle, and then back through Sagittarius, the Archer, on the right to return to Pisces, the Fish.

In an Elizabethan translation of the *Arte de Navegar*, Martin Cortes explains that "The Sunne and the Moone are mooved under the Zodiacke with divers motions. The Moone with a swifter motion then the Sunne followeth him, overtaketh him, and goeth before him, until she place herself in Diameter with him. And when shee hath thus overtaken him, so that they are both in one self same degree of the Zodiacke, then is the conjunction. Then departing from him, and being in equall degrees of the signes opposite according to the Diameter, is the opposition." The new moon occurs at conjunction, and the full moon at opposition (see Figure 15).

The sun moves through the zodiac roughly once in 365¼ days. This period defines the year in the Julian calendar. Introduced by Julius Caesar in 46 B.C. and used until 1582, when it was replaced by the Gregorian in certain parts of Europe, the Julian calendar had three consecutive years of 365 days each and a fourth, the leap year, of 366 days. (The modern Gregorian calendar skips one leap year in every century that is not a multiple of 400.)

The moon moves through the zodiac in roughly 29½ days so that twelve revolutions of the moon occur in 354 days, eleven days short of the regular year and twelve days short of the leap year. It is clear that if the new moon occurs on January 1 of one year, it will not occur on January 1 of the next. The epact number gives the moon's age on the first day of January. The epact numbers repeat after nineteen years because the moon and the sun

15. Diagram illustrating the phases of the moon. From the first edition of Petrus Apianus's Cosmographicus Liber (Landshut, 1524). This diagram shows why certain portions of the moon are visible from the earth at certain times of the month. The eye is that of an observer on earth. The new moon or the conjunction of the moon and sun is shown at the top of the circle; the full moon or opposition of the moon and sun is at the bottom. Woodcut, 5¾ x 7⅞ inches. The New York Public Library, Rare Book Division



assume almost the same relative positions in the zodiac after this interval. For example, if the epact number is 1 in 1606, it will be 12 or 1 + 11 in 1607, and 1 again in 1625. Using the epact number and the old prescription "Thirty days hath September . . . ," it is a simple matter to calculate the age of the moon on the first day of any month and consequently the dates of the full moon during the course of the year.

The definition of Easter requires the knowledge of the date of the first full moon after the vernal equinox, that is, the day when the sun in its travels around the zodiac ushers in the spring by crossing the equatorial plane (at the sign of the Ram in Figure 14). In the Julian calendar used by the Christian church the vernal equinox was assigned to the twenty-first day of March every year. To find the day of Easter the Sunday after the first full moon after March 21 also had to be found, and this required further calculation. To facilitate the calculation a system of letters was introduced. The first seven days of the year were assigned the letters A through G, and these letters were repeated in the same order throughout the year. Thus every day of the year had a letter. The letter assigned to the day upon which the first Sunday of the year fell was called the Dominical or Sunday Letter. Except in leap years every day assigned this letter was a Sunday. In England, a rhyme was often used to remember the letters assigned to the first day of each month: "At Dover Dwells George Brown Esquire, Good Christopher Finch, And David Frier," the first of January being A, the first of February D, and so on. For example, if the first Sunday of the year happened to be on the fifth of January, the Dominical Letter would be E. Using the rhyme, Sunday would fall on February 2, March 2, April 6, and so on. The other Sundays during each month could then be determined easily.

In the case of a leap year the above convention applied until February 28, which was always a C in the day-letter system. The extra leap-year day, February 29 (in the sample year mentioned above it would be a Saturday), did not receive a letter of its own. Consequently, March 1, always D, advanced a day in the week (in the sample year from Saturday to Sunday), in essence moving all the day letters backward by one. This meant that the Dominical Letter used through February would be replaced by a new one indicating the first Sunday in March and determining Sundays for the remainder of the year. Thus, if our example year were a leap year the new Dominical Letter would be D, and according to the rhyme Sundays would fall on March 1, April 5, and so on.

All these calculations rested on the suppositions that the year was exactly 365¼ days long and the period of the moon was 29½ days. Both these assumptions were not quite accurate. Furthermore, no account was taken in the Julian calendar of the procession of the equinoxes, the change in the position of the sun in the zodiac as it crosses the equatorial plane, caused by the wobble in the earth's axis. By the sixteenth century, the errors were so great that the vernal equinox occurred ten days before March 21. Reform was absolutely necessary, and in the year 1582 the new Gregorian calendar was adopted, though not universally. The English authorized its adoption as late as 1750. In Germany, the Catholic states adopted the reformed calendar in 1582, while the Protestant states used the Julian calendar until 1700. Epact numbers on German instruments of the seventeenth century are often given for both the Gregorian and Julian calendars.

The Night Hours

While our year is defined by the apparent motion of the sun and the lunar month by the motion of the moon, the day is determined by the rotation of the earth about its axis. The sundial, for example either in Figure 2, measures the earth's rotation by dividing into equal hours the period during which the shadow cast by the style twice falls on the line marked twelve. The sundial day is thus defined as lasting from noon to noon.

The way in which the dial can be used to record the hours of the night with the help of the volvelle is best illustrated on the night of the full moon, when the age of the moon

16. Celestial Map, Northern Hemisphere, by Albrecht Dürer, with the nocturnal from Figure 7 seen against a portion of the map. The relative positions of Ursa Major and Ursa Minor can be seen to the left of the instrument. The Guards of Ursa Major, stars 16 and 17, are on a line with the North Star in the tail of Ursa Minor. While many nocturnals measure the apparent motion of the Guards around the North Star, this nocturnal makes use of the star marked 6 in Ursa Minor and the North Star in order to tell time at night. Woodcut, detail 9¾ x 7¼ inches. German (Nuremberg), 1515. Harris Brisbane Dick Fund, 51.537.1


Telum
Auis
Ophiuchus
Hercules
Lyra
Cepheus
Cassiopeia
Corona
Anguis
Draco
Vrſa minor
Vrſa maior
Gemini
Cancer
Leo
Virgo
ARIES
TAVRE
GEMIN
CANC
VIRG
LIBRA
SCORP
SAGITA
CAPRI
AQVAR
PICES
DE FOY

is 14¼ days. On this night, the moon is in opposition to the sun (see Figure 15), that is, directly opposite the sun in the circle of the zodiac. At midnight, when the earth has completed half its daily rotation, the moon is in the same relative position to the earth as was the sun at noon at the beginning of the sundial day. The shadow cast in moonlight will then fall on the line marked twelve. The other equal hours before and after midnight for this particular night will be the same as the sundial hours.

If the volvelle in Figure 3 is set at 14¼, the hours on the brass and the ivory circles will coincide. For the other nights of the month, the moon's orientation to the earth at midnight will be different from the sun's orientation to the earth at midday. In order to compensate for this difference, the volvelle is rotated to the appropriate night of the lunar month and the corrected hour is read off. Because the lunar month is roughly 29½ days long the compensation necessary for each night is approximately 1/29 of a circle.

The period recorded by the shadow between noon and noon, a sundial day, does not quite correspond to one revolution of the earth around its axis. The day is a little less than one complete revolution, because the sun will have moved approximately 1/365 of its yearly course through the zodiac in the time the earth has made a single revolution, and the two motions are in opposite directions.

For every complete revolution of the earth, an observer would see the sphere of the fixed stars rotate once around a north-south axis (see Figure 14). The star Polaris, the North Star, is very close to the celestial north pole, so that the stars in the northern hemisphere seem to rotate around Polaris. The time at night was measured historically by the motions of Ursa Minor (the Little Bear or Little Dipper) and Ursa Major (the Great Bear or Big Dipper) around the North Star, because the first constellation contains the North Star in its tail (the star labeled 1 of Ursa Minor in Figure 16) and the second constellation contains two stars called the Guards (the stars labeled 16 and 17 of Ursa Major), which lie on a line with the North Star and are especially easy to find in the night sky (see Figure 16). Nocturnals were built to measure the motion of either of these constellations or both.

In order to compensate for the difference between the day measured by the sun and the time it takes the earth to make one complete revolution, the hour dial of the nocturnal has to be moved ahead approximately 1/365 of a circle (or about 1°) every day. Because of the phenomenon of the procession of the equinoxes caused by the wobble of the earth's axis, a nocturnal cannot be used over a period of very many years. For example, in four centuries the distance from the North Star to the pole has shifted about two degrees.

REFERENCES

Further material concerning the calendar and the date of Easter can be found in the entries for those subjects in the eleventh edition of the *Encyclopaedia Britannica*, Vols. IV and VIII (New York, 1910), and in Sir S. H. Jones's chapter (21) in Vol. III, *A History of Technology*, ed. by Charles Singer (Oxford, 1957). An interesting discussion of the problem of determining the date of Easter in the early Church can be found in Louis Gougaud's *Christianity in Celtic Lands* (London, 1932). The English translation of the letter from the Emperor Constantine to the bishops was taken from pp. 51-54 of Isaac Boyle's *Historical View of the Council of Nice with a Translation of Documents* (New York, 1842).

A good description of the construction of a moon dial and a nocturnal can be found in Book VIII, Chapter 6, of the English translation of Nicolas Bion's *The Construction and Principal Uses of Mathematical Instruments* (London, 1723). D. W. Waters's essay "Science and the Techniques of Navigation in the Renaissance," an excellent discussion of the use of the circumpolar stars and the moon's phases by sixteenth-century navigators, can be found in *Art, Science and History in the Renaissance*, ed. by Charles S. Singleton (Baltimore, 1967), pp. 189-237.

For information concerning the Troschels see Ernst Zinner's *Astronomische Instrumente des 11. bis 18. Jahrhunderts* (Munich, 1956) and "Three Nürnberg 'Kompassmacher' " by Bruce Chandler and Clare Vincent to be published in the *Metropolitan Museum Journal*, Vol. II (New York, 1969). For the way in which sundials work see the authors' article "A Sure Reckoning" in *The Metropolitan Museum of Art Bulletin*, 26 (1967), pp. 154-169.