A ROMAN SUN-DIAL

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Descriptions and pictures of the various kinds of portable sun-dials usually include a small compact instrument briefly called a "Roman Dial". There seems to be nothing in print that describes its working principles or analyzes the mathematics on which it is based. It turns out to be surprisingly ingenious in its construction, and it accomplishes something quite different from what is generally supposed. Figure 1 is a photograph of such an instrument in the Evans collection, now in the Museum of the History of Science at Oxford University. It is a bronze disk with a diameter of 60.5 millimetres. It dates from about 250 A.D. At the top is a small ring that was used for attaching a cord, now lost, from which the dial was suspended. The edge of the upper right quadrant is divided into ten-degree intervals, beginning with XXX, 30° in Roman numerals, and ending with LX, 60° in the same notation. The circle just inside the calibrations is the edge of a second smaller disk, countersunk in the first. The smaller disk rotates on a central pivot which also carries a peculiarly shaped object that combines both the gnomon and the actual dial plate. The smaller disk is marked with a diameter largely obscured by the dial plate. On either side of this diameter are short portions of radii at a distance of 23½°. One of these is marked VIIIKIVL, and the other VIIIKIAN, eight days before the kalends of July and January respectively. Those who remember the Roman calendar from their study of Caesar and Cicero will easily translate these dates into June 24 and December 25 in modern notation. They indicate the summer and winter solstices at the time the dial was made. The smaller disk is also marked with a radius at right angles to the diameter. The disk is to be turned so that this radius comes under the figure for the observer's latitude as shown on the outer quadrant. In the photograph, the setting is for about 47° of latitude. On the back of the dial is a table giving latitudes of thirty places from EGYPT XXX in the south to BRIT LV in the north.

Turning to the central object, the gnomon is the perpendicular projection at the left. The dial plate is the long, narrow, surface that begins at the base of the gnomon and curves upward to the right. The hour lines run across this and are not numbered. Five are marked, and the end of the curve makes a sixth. This central object is to be turned

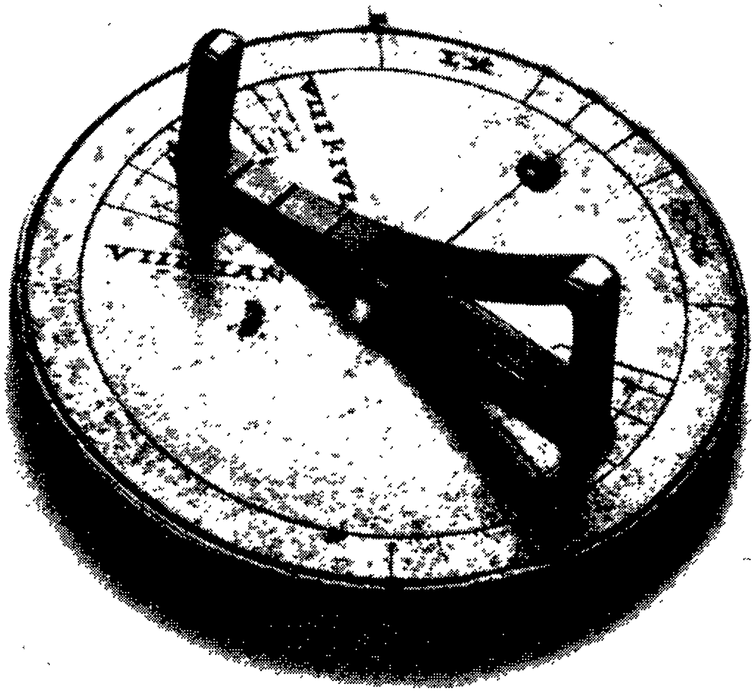

FIG. 1—Roman sun-dial, slightly larger than the original. (Courtesy of the Curator of the Museum of the History of Science, Oxford.)

on the pivot so that it takes its proper place between the solstice lines in accordance with the sun's declination on the date that the dial is used. As nearly as can be read from the photograph, the setting is for either ten days before the vernal, or ten days after the autumnal equinox.

The dial is used as follows: 1. Set the smaller disk for the observer's latitude. 2. Set the gnomon for the date the observation is made. 3. Pick up the dial by the cord and turn it until the shadow of the gnomon lies wholly on the dial plate without falling askew on either side. 4. The end of the shadow of the gnomon gives the hour by its position among the hour lines. Some persons have jumped to the conclusion that the Roman Dial is only the much commoner Universal Ring Dial with the equatorial ring somewhat compressed for ease in carrying. This is too much of a simplification and obscures its true nature. Neither is it an astrolabe, although some astrolabes have such a dial among their accessories.

To turn to its astronomical principles, in figure 2 is a side elevation of the dial plate and gnomon. *AB* is the gnomon, *BC* the edge of the dial plate. The various hour lines are projections of the corner, *A*, onto the dial plate made by rays from the sun 15° apart. The plate is curved, simply so that a shadow at noon, when the ray of sunlight is on the

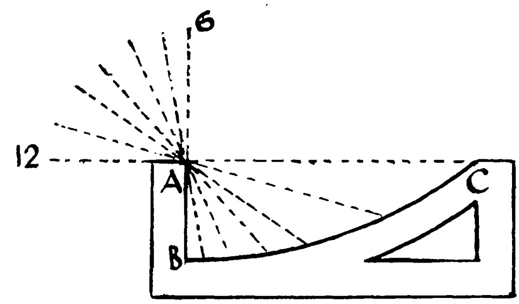

FIG. 2—Side elevation of the dial plate and gnomon.

line 12*AC*, will not be infinitely long. Note that a ray of sunlight during the afternoon will sweep from the line 12*AC*, down the line *CB*, to the line 6*AB* at evening. As *A*, *B*, and *C* lie in a plane, the rays of light have swept over a plane surface. Projecting the rays backward shows that they must intercept the celestial sphere with a plane surface. Point *A* is to be considered as at the centre of the celestial sphere. A plane through the centre of a sphere intercepts the surface on a great circle.

To take an example in middle latitudes, figure 3 shows the visible portion of the celestial sphere with the gnomon at the centre. The

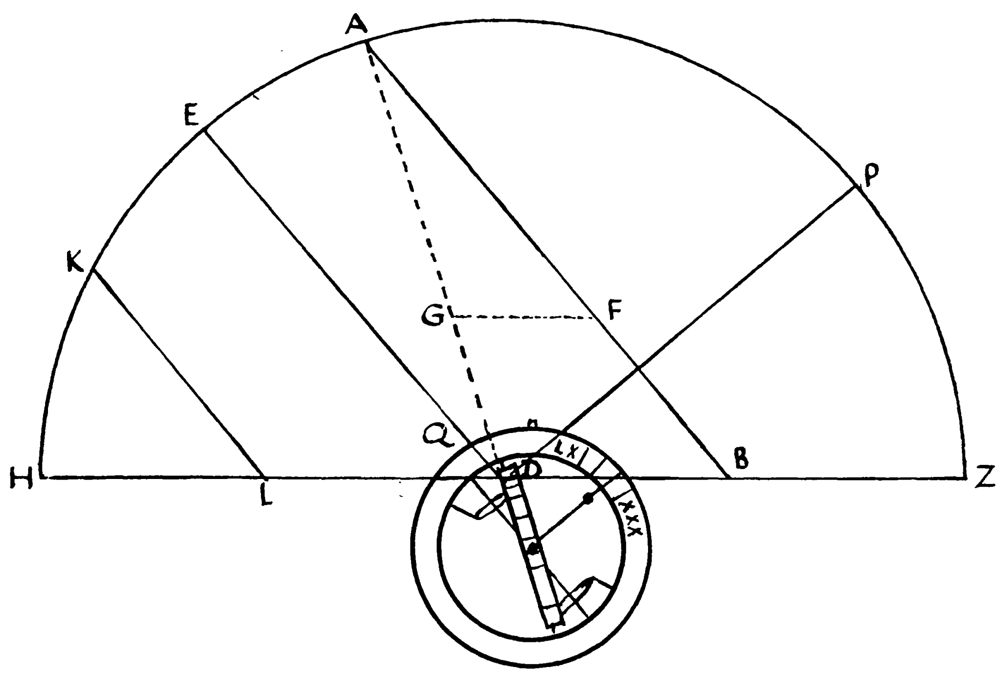

FIG. 3—The visible portion of the celestial sphere with the gnomon at the centre.

latitude is 40° north. *P* is the north celestial pole, *EQ* the celestial equator, *HZ* the horizon. Let the date be the summer solstice and let the hour be sunrise. If the sun's path lay along *D G A*, a great circle seen edgewise, it would be possible to turn the dial into the plane of the meridian, and for the entire morning the shadow would stay on the dial plate, growing steadily longer, until at noon the plate would be entirely covered. In fact, the sun's path on this date is *B F A*, substantially coincident with the Tropic of Cancer, and is not a great circle. Consequently, at sunrise the gnomon will cast a horizontal shadow unless the dial is twisted out of the meridian by an angle that subtends arc *DB*. When this is done, the gnomon points to the sun and there is no shadow at all. When the sun has risen to point *F*, the dial must depart from the meridian by a smaller angle measured by arc *GF*, and so on until the dial comes into the meridian at noon, with the sun at *A* and the plate entirely covered with shadow. This twisting of the dial causes it to follow the sun as if its path was *D G A*, althought it is in fact *B F A*. As the dial simply measures the sun's altitude, it follows that it can also handle the problem in the afternoon without change of setting, but analysis is more complicated. Suffice it to say that the dial swings much farther out of the meridian, and after a turn of more than 180° points directly to the sun at sunset.

The point to notice is that this dial always reads exactly six hours from noon at sunrise and sunset, even on long days in summer and short ones in winter. It is incorrect to assume that it is hopelessly in error. What we have is not an equal hour dial, such as the Universal Ring, as some have supposed, but one that gives the old "unequal hours"; that is, twelve hours from sunrise to sunset regardless of the length of the day. This form of time division, with long daylight hours in summer and short in winter, seems bizarre today; but when sun-dials were taken seriously, even kings and emperors had to cease most activities at sunset because of poor artificial lighting. Under such conditions it would be more important to know what proportion of the daylight remained than the exact position of the earth in its rotation. Then they were not bothered with withholding and time-and-a-half overtime. Many old sun-dials, fixed and portable, are designed to give a reading in unequal hours, and early astronomers were concerned with the problem of converting one kind of hour into the other. For an example readily accessible, though at a later period, see Chaucer's *Astrolabe*. Part II, propositions 7 through 11, are concerned with this.

If this is an unequal hour dial, it remains to be seen whether or not it gives an accurate reading. In figure 3 the sun's semi-diurnal arc, *B F A*, is substantially more than a quarter circle. At the winter solstice it will be along *KI* and less than a quarter circle by the same amount, but the dial plate is calibrated on the assumption that the semidiurnal arc is an exact quarter circle. This is true only at the equinoxes. Figure 4 shows the various semidiurnal arcs for 40° arranged for comparison. All are divided according to the unequal hour system. While the divisions do not agree exactly, they are so close that the dial is able to accomplish

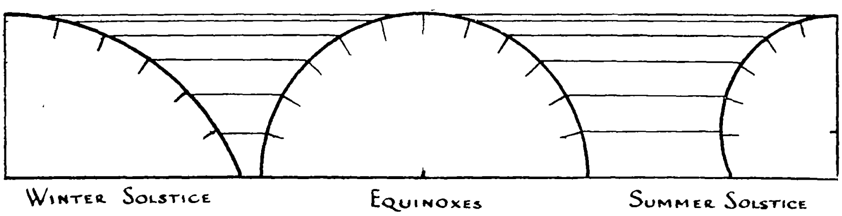

FIG. 4—Semidiurnal arcs for latitude 40°.

its purpose much better than might be supposed. Trigonometric calculations will reveal that in latitude 40° the maximum error is less than fifteen minutes of time. This would be negligible in the age when the dial was made.

Altitude dials, with unequal hours, are fairly common, but few are adaptable to different latitudes, and most of them require the solving of many spherical triangles in their construction. The Roman Dial can be used in many latitudes. Its construction is mathematically simple. It furnishes a highly ingenious solution of a complex mathematical problem and excellently illustrates the geometrical acumen of the early astronomers.