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SUNDIALS

Contents

I. Introduction

One of the earliest methods of determining time was by observing the position of the shadow cast by an object placed in the sunshine. As the day advances the shadow changes and its position at any instant gives an indication of the time. The relative length of the shadow at midday can also be used to indicate the season of the year. It is thought that one of the purposes of the great pyramids of Egypt was to indicate the time of day and the progress of the seasons.

Although the origin of the sundial is very obscure, it is known to have been used in very early times in ancient Babylonia. One of the earliest recorded is the Dial of Ahaz, 8th Century, B. C., mentioned in the Bible, II Kings XX:8-11. The Greeks used sundials in the 4th Century B. C. and one was set up in Rome in 293 B. C.

Today sundials are used largely for decorative purposes in gardens or on lawns, and many inquiries have reached the Bureau of Standards regarding the construction and erection of such dials. This paper has been prepared to give in a brief form information which will be useful in the construction of sundials.

II. Corrections to be applied

The sundial, in its usual form, consists of two essential parts, a straight edged indicator or gnomon, for casting a shadow, and a suitably graduated dial on which the shadow is cast.

Sundials indicate true local sun time which differs from mean solar time by varying amounts throughout the year. It is therefore necessary to apply to indications of a sundial a variable correction known as the equation of time. (See Table on page 3). It is usually necessary to apply a further correction because of the fact that in most localities standard time, rather than local time, is used and few places are located exactly on the standard meridian. This correction is constant and depends upon the difference in time, or longitude, of the standard meridian of the time zone in which the sundial is to be located and that of the particular place of location. This correction can be calculated on the basis of 15° longitude difference being equivalent to a time difference of one hour. For positions to the West of the standard meridian the correction must be added to the sundial reading and to the East it must be subtracted.

The standard meridians of the various time zones of the United States are as follows: - eastern, 75th; central, 90th; mountain, 105th; Pacific, 120th. The longitude and time correction for any given locality can be obtained from maps or tables or from authentic records.

EQUATION OF TIME

The values given below are to be added algebraically to the reading of the Sundial to obtain Mean Solar Time. Values are given to the nearest five seconds and are average values for a four-year period. During the latter part of December and the first part of January, the time of greatest daily difference, this table may be in error for specific dates by as much as 20 seconds. The variation from the values given at other times is generally less than 10 seconds. (See Nautical Almanac for more exact values for any given year.)

Day of Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
1	+3:30	+13:40	+12:30	+4:00	-2:55	-2:25	+3:35	+6:10	0:00	-10:15	-16:20	-10:55
2	+4:00	+13:50	+12:20	+3:40	-3:05	-2:15	+3:45	+6:10	-0:20	-10:35	-16:20	-10:35
3	+4:25	+13:55	+12:05	+3:25	-3:10	-2:05	+4:00	+6:05	-0:35	-10:55	-16:20	-10:10
4	+4:55	+14:00	+11:55	+3:05	-3:15	-1:55	+4:10	+6:00	-0:55	-11:10	-16:20	-9:45
5	+5:20	+14:05	+11:40	+2:50	-3:25	-1:45	+4:20	+5:55	-1:15	-11:30	-16:20	-9:25
6	+5:50	+14:10	+11:25	+2:30	-3:30	-1:35	+4:30	+5:45	-1:35	-11:50	-16:20	-9:00
7	+6:15	+14:15	+11:10	+2:15	-3:30	-1:25	+4:40	+5:40	-1:55	-12:05	-16:15	-8:30
8	+6:40	+14:20	+10:55	+1:55	-3:35	-1:10	+4:50	+5:30	-2:20	-12:20	-16:10	-8:05
9	+7:05	+14:20	+10:40	+1:40	-3:40	-1:00	+5:00	+5:25	-2:40	-12:40	-16:05	-7:40
10	+7:30	+14:20	+10:25	+1:25	-3:40	-0:50	+5:10	+5:15	-3:00	-12:55	-16:00	-7:10
11	+7:55	+14:25	+10:10	+1:05	-3:45	-0:35	+5:15	+5:05	-3:20	-13:10	-15:55	-6:45
12	+8:20	+14:20	+9:55	+0:50	-3:45	-0:25	+5:25	+4:55	-3:40	-13:25	-15:50	-6:15
13	+8:40	+14:20	+9:40	+0:35	-3:45	-0:10	+5:30	+4:45	-4:00	-13:40	-15:40	-5:50
14	+9:05	+14:20	+9:20	+0:20	-3:45	0:00	+5:40	+4:35	-4:25	-13:55	-15:30	-5:20
15	+9:25	+14:20	+9:05	+0:05	-3:45	+0:15	+5:45	+4:25	-4:45	-14:10	-15:20	-4:50
16	+9:45	+14:15	+8:50	-0:10	-3:45	+0:25	+5:50	+4:15	-5:05	-14:20	-15:10	-4:20
17	+10:05	+14:10	+8:30	-0:25	-3:45	+0:40	+5:55	+4:00	-5:25	-14:35	-15:00	-3:55
18	+10:25	+14:05	+8:15	-0:35	-3:45	+0:50	+6:00	+3:50	-5:50	-14:45	-14:50	-3:25
19	+10:45	+14:00	+7:55	-0:50	-3:40	+1:05	+6:05	+3:35	-6:10	-14:55	-14:35	-2:55
20	+11:05	+13:55	+7:40	-1:05	-3:40	+1:20	+6:10	+3:20	-6:30	-15:05	-14:20	-2:25
21	+11:20	+13:50	+7:20	-1:15	-3:35	+1:30	+6:15	+3:05	-6:50	-15:15	-14:05	-1:55
22	+11:40	+13:40	+7:00	-1:30	-3:30	+1:45	+6:15	+2:50	-7:15	-15:25	-13:50	-1:25
23	+11:55	+13:35	+6:45	-1:40	-3:25	+1:55	+6:20	+2:35	-7:35	-15:35	-13:35	-0:55
24	+12:10	+13:25	+6:25	-1:50	-3:20	+2:10	+6:20	+2:20	-7:55	-15:45	-13:15	-0:25
25	+12:25	+13:15	+6:05	-2:00	-3:15	+2:20	+6:20	+2:05	-8:15	-15:50	-13:00	+0:05
26	+12:35	+13:05	+5:50	-2:15	-3:10	+2:35	+6:20	+1:50	-8:35	-15:55	-12:40	+0:35
27	+12:50	+12:55	+5:30	-2:25	-3:05	+2:50	+6:20	+1:30	-8:55	-16:05	-12:20	+1:05
28	+13:00	+12:45	+5:10	-2:30	-2:55	+3:00	+6:20	+1:15	-9:15	-16:10	-12:00	+1:35
29	+13:10	+12:35	+4:55	-2:40	-2:50	+3:10	+6:20	+0:55	-9:35	-16:10	-11:40	+2:05
30	+13:20		+4:35	-2:50	-2:40	+3:25	+6:15	+0:40	-9:55	-16:15	-11:20	+2:35
31	+13:30		+4:15		-2:30		+6:15	+0:20		-16:20		+3:00

III. Construction

Sundials have been built in many forms, some of which are very unusual. The determination of the correct positions of the graduation lines on sundials, known as the science of gnomonics, is very complicated. A list of references of sundial construction is given later in this paper. The most common form of sundial is the horizontal dial with a vertical gnomon. Directions for the laying out of a dial of this type for the northern hemisphere are given here.

1. Materials and foundation

In choosing the material on which to lay out the dial, consideration should be given to durability, resistance to weather, and legibility. A thickness of not less than one-quarter of an inch is recommended to assure rigidity of the surface. Bronze or gun metal are generally used and seem to be very satisfactory under the conditions to which they are exposed. Stainless steel stands up well and is not subject to marked discoloration. A plate of optical glass about one inch thick with the etched lines might serve very well, but is subject to breakage and chipping. Copper, aluminum, brass, silver, German silver, and most of the other common metals are subject to tarnish or oxidation and in a short time the lines become indistinct. Iron rusts too easily to make a good sundial material. The use of chromium plate on a base of some of the metals mentioned might make a very good dial material.

To avoid any possibility of electrolysis, the gnomon and any screws making contact with the dial should be of the same material as the dial.

A good concrete or stone foundation on a firm base makes the most satisfactory means of assuring stability of mounting. The pedestal upon which the dial is to be mounted must be secured to this foundation in a manner to make it perfectly rigid. Materials for the pedestal must be durable and firm. Concrete, marble, stone, or brick make very good pedestals. Wood is not suitable for either the pedestal or the dial because of likelihood of distortion and decay.

2. Graphical construction for a horizontal sundial

Draw the vertical line A B (See Fig. 1).

Near the middle of A B mark point C and draw a horizontal line through it.

Measure off C D a convenient length (e.g. 10 cm).

Lay off C E = C D × sine of latitude angle.

Through E draw the horizontal line E F.

With E as a center describe arc F G of any convenient radius.

Divide this arc into 15° parts representing the hours from 12 vertical to 6 horizontal.

Draw radii through these points and E extending them to cut the horizontal line C H.

Connect each of these intersecting points with D. These last lines are the hour lines of the dial, with the vertical line (D C) the 12 line, and the horizontal line the 6 line.

The subdivisions of the hour may be obtained in the same way by further subdividing the arc F G.

This gives one half the dial.

Draw line A' B' parallel to A B and a distance from it equal to the thickness of the gnomon to be used.

Extend the horizontal line H C and lay off on it distances from L toward M equal to the distances from C of the intersections of the time lines on C H.

Connect these points to J and the morning time lines from 6 a.m. to 12 noon have been established.

To obtain the 5 a.m. and 7 p.m. lines extend the 5 p.m. and 7 a.m. lines, respectively, from the opposite side of the dial. This is necessary because the shadow for these hours is cast by the opposite side of the gnomon.

The dial itself may be made of any desired form and the time lines extended to cut the border lines of the dial. (See Fig. 2)

3. Gnomon

The angle of the indicating edge of the gnomon with the horizontal plane must be equal to the latitude of the location.

The length of the gnomon must be great enough to cast a shadow of sufficient length to intersect the reading scale of the dial.

The gnomon must point to the true North. It will then be in the plane of the local meridian.

The form of the lower part or the thickness of the gnomon does not affect the reading.

4. Mathematical construction

For those who prefer the mathematical method of laying out the dial, the following formula is offered.

$$\tan A = \tan a \sin L$$

where

A is the time angle formed at D on the diagram

a is the hour angle of the sun and is equal to 15 degrees for each hour on the time scale

L is the latitude of the location.

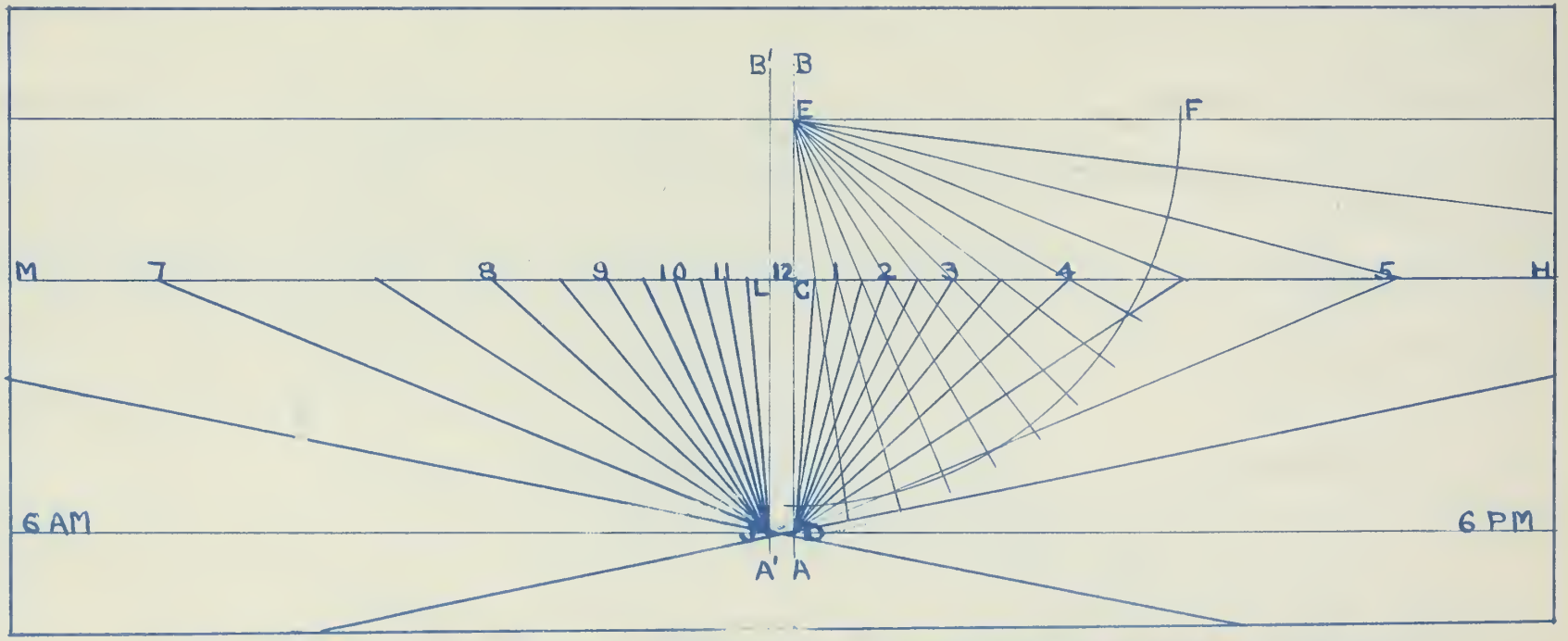

FIGURE 1. GRAPHICAL CONSTRUCTION FOR HORIZONTAL SUNDIAL.

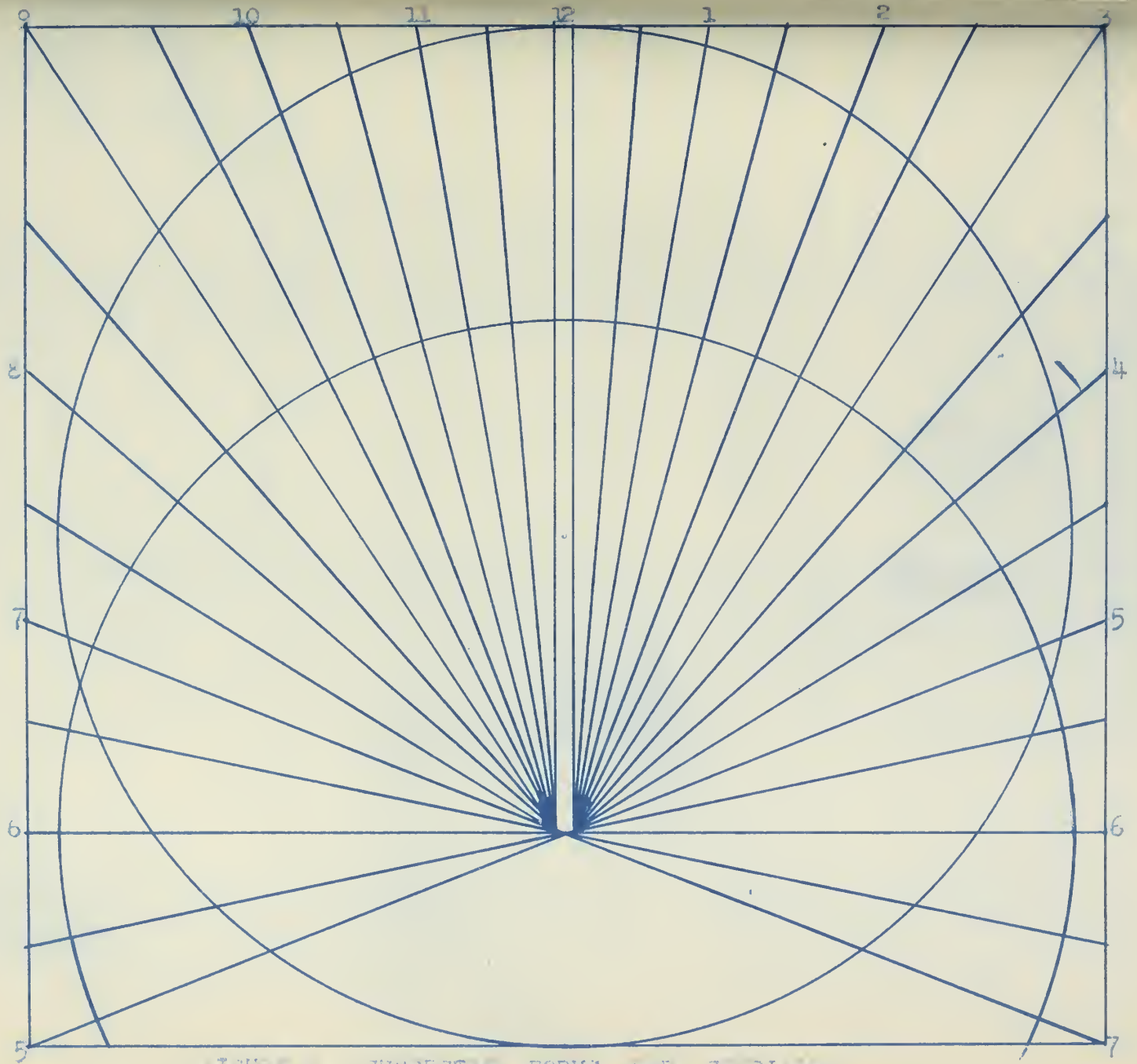

FIGURE 1. SUGGESTED FORMS FOR [illegible].

IV. Setting up the dial

After the construction of the dial and gnomon has been completed, there remains the placing of the sundial in its proper position. As the operation of the dial depends upon the shadows cast by the gnomon, an open space with a clear southerly exposure should be chosen. The dial should be set perfectly level, with the 12 o'clock line pointing to the true geographic north. A compass points to the north magnetic pole, and if the setting is done by compass a correction in setting must be made to place the dial on the meridian. This correction is known as magnetic declination and can be obtained from tables.

A simple method of orienting a sundial and a fairly reliable one if carefully done, is to calculate the corrections for the 12 o'clock shadow and mark on the dial a spot to show the corrected location of noon for some particular day and then to set the dial so that the noon shadow on that day will fall on the spot marked.

If the setting is properly done, the dial will then be on the local meridian, the gnomon will point to the true North, and the shadows cast by the gnomon will give the true local time.

V. Mottoes

It is often the custom to inscribe on the sundial some appropriate motto. We give here a few samples of brief mottoes which have been used for this purpose. Additional mottoes, and more lengthy ones, will be found in the books listed in the bibliography.

The light guides me, the shadow you.

I show only sunny hours.

Time waits for no man.

The hour passed cannot be recalled.

You ask the hour, meanwhile you see it fly.

I mark the moments trod for good or ill.

I mark time, do'st thou?

Hour passes into hour.

Watch for ye know not the hour.

Time passeth and speaketh not.

VI. Bibliography

The subject of dialling or gnomonics is touched on in most encyclopedias and in a large number of published works. A few of these are listed below:

The following are the oldest known books on sundials:

1. Vitruvius, "De Architectura"

2. Ptolemy, "Almagest"

The following treat of sundials in general:

3. Britten, F. J., "Old Clocks and Watches and Their Makers", (Pages 5-9), London, 1922

4. Brown, John, "The Art of Dyalling, 1671

5. Dawbarn, "The Sundial", London, 1891

6. Dodwell, G. F., "The Cooke Sundial", 1910

7. Dyer, Walter A., "Sundials in Modern Gardens", Country Life in America, March, 1906

8. Earle, Alice Morse, "Sundials and Roses of Yesterday", New York, 1902

9. Gatty, Mrs. Alfred, "The Book of Sundials", London, 1889

10. Green, A. R., "Sundial", 1926

11. Henslow, Thomas Geoffrey Wall, "Ye Sundial Booke", London, 1914

12. Hogg, Warrington, "The Book of Old Sundials - Their Mottoes", London, 1917

13. Horne, D. E., "Primitive Sun Dials or Scratch Dials", 1917

14. Jacoby, Harold, "Astronomy", Chap. V., New York, 1913

15. Spackman, Henry Spencer, "The Timepiece of Shadows, A History of the Sundial", New York, 1895.

The following contain many mottoes which have been used on sundials:

16. Hyatt, Alfred H., "Book of Sundial Mottoes", London, 1903

17. Rawlings, Alfred, "Book of Sundials and their Mottoes", 1915

18. Spackman, Henry Spencer, "The Timepiece of Shadows".

The following deal with the construction of sundials:

19. Barlow, C. W. C., & Bryan, G. H., "Mathematical Astronomy", page 129, 1930

20. Brown, F. Willard, "A Simple Method of Laying Out a Sundial", Scientific American, Vol.101, p.355.

21. Crehore, A. C., "A Scientific Elucidation of Sundials", Jewelers Circular, June 5-26, 1907.

22. de Celles, D. F. B., "La Gnomonique Pratique",1760

23. Fale, Thomas, "The Art of Dialling", 1626

24. Foster, Samuel, "The Art of Dialling", 1638

25. Heath, Charles, "How to Make a Horizontal Sundial", The Keystone, February 15, 1912

26. Hirsberg, Leonard K., "A Pocket Sundial", Scientific American, August 10, 1912

27. Jacoby, Harold, "Practical Talks by an Astronomer", (Pages 69-80), New York, 1902

28. Leybourn, William, "Dialling", 1700

29. Milham, W. I., "Time and Timekeepers", page 44, New York, 1923

30. Mitchell, J. E., "How to Lay Out a Sundial", The Keystone, April 1911

31. Pettit, Edison, "A Method of Finding the Meridian by Shadows and Mechanically Graduating a Sundial", The Keystone, January 1911

32. Reinecke, H., "Sundials that Beautify the Landscape", Jewelers Circular, June 30, 1909.

33. Spackman, "The Timepiece of Shadows"

34. "Sundials and Dialing", American Jeweler, July 1917

The following is the most reliable table for the equation of time:

35. The American Ephemeris and Nautical Almanac, prepared by the U. S. Naval Observatory.