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CAPE ASTRONOMICAL ASSOCIATION.

THE EQUATORIAL SUNDIAL

ERECTED AT

THE CASTLE, CAPE TOWN.*

By JOSEPH LUNT, D.Sc., President, 1917–1919.

The sundial is among the most ancient of astronomical instruments, for ever since man began to take note of the passage of time he has looked to the sun as the time measurer, not only for the day, but for the year, and no almanac even at the present day is complete without the times of sunrise and sunset, and the dates of the equinoxes and the summer and winter solstices.

Before the advent of clocks, sundials were of much more general use and importance than they are now, and they have taken so many varied forms that it is easily possible to have a different design for every day of the year. The support itself has afforded scope for the work of the artist and the sculptor, and has often been the most striking and prominent part of the sundial. Those who wish to know more of the subject should procure the delightfully written and beautifully illustrated book entitled "Sundials and Roses of Yesterday," by Alice Morse Earle.

Before uniformity of time throughout a country was rendered necessary by the advent of the railway and the telegraph, sundials always showed local solar time, just as ships at sea do to-day, and high noon was always twelve o'clock. It mattered not that at the same instant a sundial in Cornwall showed a different time from

* Based on a description given before the Association by the President on May 14, 1919.

one in Kent; every village kept its own time and was quite content with the arrangement. It mattered not that sundial time was not uniform and that the interval from mid-day to mid-day varied; a quarter of an hour either way was a matter of indifference.

Chambers* tells us that "in France, until 1816, apparent time was used, and the confusion arising from this practice may be readily imagined. Arago relates that he was once told by Delambre that he had frequently heard the different public clocks striking the same hour with a variation of thirty minutes. At the time of the change to mean time the Prefect of the Seine refused to sign the necessary order, fearing an insurrection of the lower classes; the worthy magistrate's fears, however, proved to be groundless. Especially were the watchmakers thankful for the change; under the old system, all in vain was it they tried to explain to their enraged customers, when they came to complain of the watches they had bought, that it was not the watches but the sun which was in fault."

There are two mural sundials in the courtyard of the Castle, when and by whom these were erected I do not know, and the rough graduations, reading only the half-hours, are probably renovations of later date. The Castle itself is, for a young country, quite an antiquity, and was founded in 1666. During his tenure of office, General Thompson undertook extensive renovations, and it was his wish to finish this work by erecting a sundial at the intersection of the two paths which cross the lawn in the courtyard, possibly the site of the Dolphin Fountain spoken of by Lady Anne Barnard in 1797. The idea was not carried out during his term of office, but he did not allow the project to drop after his departure, but left it in the hands of Sir Lewis Michell. Sir Lewis endeavoured, unsuccessfully, to acquire an old Dutch sundial, and, when consulted, I urged him, if he erected a sundial at all, to have one which would show the time as accurately as possible. He adopted my proposals and designs, which were capably carried out by Mr. T. R. Miller, Mechanician to the Royal Observatory, the entire cost being borne by the Rhodes Trustees.

The general appearance of the sundial and details of the metalwork are shown in the two illustrations. In Mr. Groves's sketch "The Kat" and one of the mural sundials are shown, with the equatorial sundial in the foreground.

It will be seen that in the design of the pedestal no attempt has been made to match the ornate work of the late seventeenth century, but, with the approval of Mr. Kendall—who took an interest in the matter from an architectural point of view, and

* Handbook of Astronomy, Vol. II., p. 420.

kindly undertook to make the working drawings—a simple monolith was erected, square at the base and tapering to an octagon at the top, 4 ft. 5 ins. above the second circular step from which the dial is approached. The material is hard Table Mountain sandstone, quarried on the mountain slopes near Camp's Bay, and al the work, including the making of patterns, casting, and graduating the metal-work, was done locally. The sundial is therefore entirely South African. Great care was taken in setting up the pedestal to orient the vertical faces exactly facing the four cardinal points; plumb lines attached to the pillar were suspended above and in line with a centre mark ruled across the octagonal top, and the pillar was rotated on its solid concrete base until star transits seen against the two plumb lines, illuminated by an electric torch, occurred at the instant of meridian passage.

Thereafter the pedestal was securely cemented to the steps with a mosaic of rough-dressed stones as a top surface, and the three Lewis bolts to hold the sundial were fixed in position by molten lead, each being held in position by a temporary templet.

With these precautions taken, the sundial was fixed centrally to the bolts on a day which happened to be cloudy, and it was subsequently found to be almost exactly in its true position, the sun throwing the shadow on the centre mark at local noon.

The principle of the equatorial sundial is easily understood if we imagine a circular table with its circumference graduated in degrees and having a central vertical rod, placed, say, at the north pole in the northern summer. As the earth rotates the graduations will, in turn, pass under the shadow of the rod, and so the passage of the hours will be shown if the graduations are appropriately numbered every 15° from $0^{h.}$ to $24^{hrs.}$

The rod, it will be observed, is in line with the earth's axis of rotation. The table and its rod may be moved to any other place on the earth's surface, and—if we take the precaution to keep the rod parallel to the earth's axis—the time will be shown just as it was at the north pole. At the equator the surface of the table will be vertical and the rod horizontal, and the north side will be lluminated during the northern summer and the south side during the southern summer. It will therefore be necessary to graduate both sides. In this case the two ends of the rod point, one to the N. pole, the other to the S. pole, the celestial poles being at opposite points of the horizon and in the meridian. At a place in latitude 45° S. the table and rod will both be inclined 45° to the horizontal, and the rod will point to the S. celestial pole. At Cape Town, therefore, the rod must lie in the meridian and must be inclined 34° to the horizontal, our latitude being 34°.

The sundial is substantially constructed of gun-metal castings, made locally. Its essential parts, shown in the illustration, are (1) the graduated half-wheel, 18 inches in diameter, which lies in the plane of the celestial equator, and (2) the central wire at right angles to it, pointing to the celestial pole. The graduated dial is supported by the semi-circular arms resting on a T-shaped base, which in turn rests on the levelling screws leaded into the stone. The dial is graduated to half degrees (two minutes of time) on a plan designed and used by Tycho Brahe, *i.e.*, marks every two and a half degrees, denoting ten minutes of time and an oblique row of four dots between the lines, the dots marking two minute intervals (see photograph). It is quite easy, therefore, to read the time accurately within half a minute, as the shadow travels a millimetre per minute. Both sides are graduated, and the shadow falls on a raised rim bevelled outwards at an angle of 45°. This gives a good shadow at the equinoxes when the rays of light from the sun fall in lines parallel to the dial itself. In summer the south (upper) face is illuminated and in winter the north (lower) face, and thus the change of seasons is clearly marked. The wire throwing the shadow is supported by the semi-elliptical arms attached to the dial, and kept taut by the flat spring screwed to the near arm. A wire has the great advantage of throwing a symmetrical shadow with a well-defined centre (seen marking the time at $4^{h.}\ 13\frac{1}{2}^{m.}$ in the photograph), whereas the usual gnomon throws a shadow with an ill-defined edge. As thus constructed and duly corrected for the equation of time, the sundial is more reliable as a timekeeper than any ordinary clock, as its errors do not acumulate. The whole can be adjusted by the levelling screws and slightly rotated in the slotted holes in the T-shaped base. It will easily be understood that this form of sundial is perfectly universal, and can be used anywhere on the earth's surface. If we take it northwards from its present position, for every degree we travel, the dial must be swung in its horizontal supports one degree nearer the vertical, until at the equator the dial is vertical and the wire horizontal. Going into the northern hemisphere the swing of the dial must be continued in the same direction until in London it is nearly $51\frac{1}{2}°$ beyond the vertical, and the lower end of the wire is elevated and points to the celestial north pole.

All other sundials can be derived from the equatorial form by projecting the graduations—by lines parallel to the wire—on to any other surface, which may be vertical or horizontal or inclined at an angle, and the surfaces may face any direction, not necessarily north and south. The essential thing is to point the wire or gnomon exactly to the celestial pole. Numerous examples may be seen in the book referred to.

We have only now to consider exactly how the graduations must be numbered.

Ships at sea keep local time and alter their clocks as they travel in longitude, four minutes for every degree or one hour every 15°. On land it is necessary to keep one uniform time throughout the country, and in South Africa the time now adopted is the local mean time of the 30th meridian east of Greenwich. Anywhere on that meridian, which passes through the central Transvaal and Western Natal, a sundial graduated in the ordinary way will show twelve o'clock at high noon (when it is ten o'clock in London), provided the equation of time, to be explained later, is zero. In Cape Town, however, high noon does not occur until 46 minutes later (46¼ minutes at the Castle), and if we wish the sundial time at Cape Town to agree with the standard time shown by clocks throughout the country we must number the division on which the shadow falls at high noon, $12^h\ 46^m$, and for any other place in South Africa we must add $4^{m.}$ to $12^{h.}$ for every degree west of the 30th meridian and subtract $4^{m.}$ from 12^h for every degree east of that meridian.

On this plan, therefore, the centres of the sundials must be marked $11^h\ 52^{m.}$ at Komati Poort and $12^h\ 52^{m.}$ at Port Nolloth, if they are to show uniform time.

Having marked the centre $12^{h.}\ 46^{m.}$ at Cape Town, we shall find if we observe the shadow every day for a year at 12 o'clock, standard time (gun-fire), that the sundial does not keep uniform time like the clocks, and is only correct four times a year. At other times it may be a quarter of an hour (roughly) fast or slow.

Some sundials are made with a means of adjusting the dial every day, or the form of the rod is altered to spindle shape, to allow for the apparently erratic behaviour of the sun. Such means of adjustment were purposely avoided as unsuitable for a dial in a public place, and owing to the danger of the adjustments getting out of order and introducing a complication. The difference between solar and mean time is, however, easily found in an almanac, such as Whitaker's, for every day of the year, and it is an easy matter to add or substract the requisite number of minutes on any day, and so obtain standard time.

Affixed to the north face of the pedestal is a brass plate showing, for every day of the year, the number of minutes the sundial is fast or slow.

Anyone desirous of understanding the reason for the above correction should make diagrams for themselves according to the following directions :—

As the earth moves in an ellipse and not a circle, it is at one point nearest to the sun and moves fastest, and at the opposite point of the orbit it is farthest from the sun and moves slowest.

Between these two points the earth moves at its mean speed. This variation of the earth's speed is reflected in the sun's apparent motion along the ecliptic of the celestial sphere. When the earth is moving fastest the sun appears to be moving fastest, and *vice versa*. So we will speak of the sun as moving, and not the earth, and mark its apparent course across the celestial sphere.

Where the sun crosses the celestial equator in March is taken as the starting point in graduating the sun's apparent path, and we will—for simplicity—mark it $0^{h.}$ (northern spring equinox) and the opposite point (autumn equinox) 12^{h}.

Mark out a circle to represent the sun's apparent path, divide it into four quadrants, and mark the ends of the diameters $0^{h.}$, $6^{h.}$, $12^{h.}$, 18^{h}, in rotation. Using the figures for 1900 as an illustration, the sun appears to move fastest at a point roughly 11° beyond $18^{h.}$; from this point (mark it perihelion, as the earth is then nearest to the sun) draw another diameter, and one at right angles to it. Mark the ends of these new diameters fastest, mean, slowest, mean, in turn, starting at the one 11° beyond 18^{h}

When the sun travels fastest, its Right Ascension is unduly increased, and it will come to the meridian unduly late every day, and therefore a sundial showing the time as 12^{h} at high noon at the period of perihelion will continue to lose for some time.

If we allow for the second correction, presently to be considered, and start a mean time clock to show 12^{h} at high noon when the sun is at the point marked perihelion, the clock will gain as compared with the sundial, or the sundial will be too slow. When the sun is at $0^{h.}$ the sundial will have lost or be too slow $7^{m.}.54$, and at the point marked "mean" it will have lost $7^{m}.68$.

From the first mean point the sundial will gradually regain the $7^{m.}.68$ it has lost (as the sun has entered the slower half of its path, and remembering that when the sun is fast the sundial is slow, and *vice versa*) until at 11° beyond 6^{h} it will agree with the clock again.

From this point (the sun going slow) the sundial will gain on the clock every day, until at the second "mean" point it will have gained $7^{m.}.68$, which it will thereafter gradually lose and agree with the clock again at the point marked perihelion, where we started.

At any point of the sun's path the correction to the sundial necessitated by the eccentricity of the earth's orbit is $7^{m.}.68$, multiplied by the sine of the angle $(L + 79^{\circ})$, L being the sun's mean longitude measured from $0^{h.}$. 79° is the angle between $18^{h} + 11^{\circ}$ and $0^{h.}$ or between the starting point (perihelion) and the northern spring equinox,

If this were the only disturbing cause, a sundial would be correct twice a year—at perihelion and aphelion—with a maximum error of $7^{m}.68$ between these two points.

A second correction has, however, to be applied owing to the effect of the obliquity of the ecliptic. The ecliptic is inclined to the equator $23\frac{1}{2}°$. If now we imagine the sun to move at a uniform rate along the ecliptic, that is, we neglect or allow for the correction just considered and suppose the earth to move uniformly in a circle; it will be evident, if we refer to a celestial globe or a star atlas, that the sun at the equinoxes crosses the celestial meridian lines obliquely where they are farthest apart, and at the solstices it crosses them at right angles where they are closer together. The effect is that the sun travels fastest in Right Ascension at the solstices $6^{h.}$ and 18^{h} and slowest at the equinoxes $0^{h.}$ and $12^{h.}$

Drawing a diagram, as before, mark $0^{h.}$ and $12^{h.}$ "sun slowest" and 6^{h} and $18^{h.}$ "sun fastest," and midway between each point mark "mean" (*i.e.*, at $3^{h.}$, $9^{h.}$, 15^{h}, 21^{h}). Starting a mean time clock to show $12^{h.}$ at high noon, when the sun is at $0^{h.}$, the sundial will gain on it each day (remembering that when the sun is unduly gaining in R.A. the sundial is losing, and *vice versa*) until the sun is at 3^{h} when the sundial will have gained $9^{m}.9$. From this point to $6^{h.}$ the sun will have entered a fastest quadrant, and the sundial will gradually lose the $9^{m}.9$ it has gained and become correct at $6^{h.}$. From $6^{h.}$ to 9^{h} the sun is still fast and the sundial will lose 9^{m} 9 and regain it at $12^{h.}$. The same cycle is repeated from $12^{h.}$ to $0^{h.}$. If the obliquity of the ecliptic alone acted, the sundial would be correct four times a year and have a maximum error of $9^{m}.9$.

At any point of the sun's path, the correction to the sundial from this cause alone is—$9^{m.}.9$ multiplied by the sine of $2\ L$. The combination of these two corrections is called the "equation of time" and is the correction shown on the brass plate.

Sometimes the longitude correction (46 minutes in this case) and the equation of time are combined as one correction and the centre of the sundial can then be marked 12^{h}; for a fixed sundial this is not advisable, and it has the further disadvantage that the equation of time as given in the almanac is no longer applicable.

The following table gives an illustration of the method of calculating the equation of time, using the figures for 1900.

Owing to the position of perihelion, the eccentricity of the earth's orbit, and the obliquity of the ecliptic changing slowly, there is a very gradual change in the equation of time, but this need not be entered into here as the corrections shown on the brass plate will hold good to the nearest minute for a very long period.

Equation of Time.

$$E = 7^{m}.68 \sin (L + 79^{\circ}) - 9^{m}.9 \sin (2L).^{*}$$

Angle from Perihelion. $(L + 79^{\circ})$	Sun's mean Longitude. (L)	First Correction. $7^{m}.68 \times \sin (L + 79^{\circ})$.	Second Correction. $-9^{m}.9 \times \sin (2L)$.	Equation of Time.	Date.
0°	281°	$0^{m}.0$	+ 3.7	+ 3.7	Jan. 2.
34	315	+ 4.3	+ 9.9	+ 14.2	Feb. 5.
79	0	+ 7.5	0.0	+ 7.5	Mar. 21.
90	11	+ 7.7	— 3.7	+ 4.0	April 1.
$103^{\circ}30'$	$24^{\circ}30'$	+ 7.5	— 7.5	0.0	„ 15.
124	45	+ 6.4	— 9.9	— 3.5	May 6.
162	83	+ 2.4	— 2.4	0.0	June 15.
169	90	+ 1.5	0.0	+ 1.5	„ 22.
180	101	0.0	+ 3.7	+ 3.7	July 4.
214	135	— 4.3	+ 9.9	+ 5.6	Aug. 8.
$238^{\circ}20'$	$159^{\circ}20'$	— 6.5	+ 6.5	0.0	Sept. 2.
259	180	— 7.5	0.0	— 7.5	„ 24.
270	191	— 7.7	— 3.7	— 11.4	Oct. 5.
304	225	— 6.4	— 9.9	— 16.3	Nov. 8.
349	270	— 1.5	0.0	— 1.5	Dec. 22.
352	273	— 1.1	+ 1.1	0.0	„ 25.

The above examples of the approximate calculation will enable anyone possessed of a Table of Sines to calculate the values for every 10 degrees of longitude, and to plot the three curves and understand why the sundial is correct only four times a year. It will readily be understood, therefore, that a sundial constructed on this simple and ancient plan is more than a mere toy, and at the outposts of civilisation, away from the telegraph, it can be used as an excellent regulator for ordinary clocks which, without some such means of correction, are far less reliable than an accurate sundial properly set up and adjusted.

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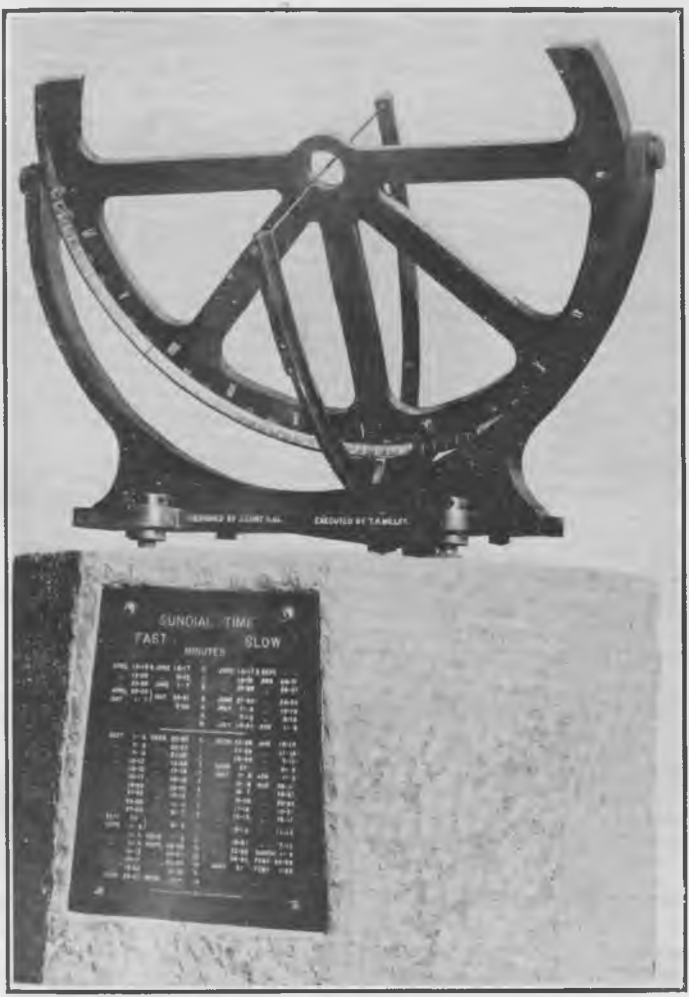
* See Ball's "Spherical Astronomy."



Inscription on South face of Dial. *Photo: Duffus.*

SINE SOLE SILEO. MCMXIX.

Presented by the Rhodes Trustees.

Courtyard of Castle, Cape Town (looking due East.) *Sketch by. C S. Groves.*

Equatorial Sundial in foreground, Mural Sundial beyond.