# The British Sundial Society

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# BULLETIN

No. 91.1 FEBRUARY 1991

# HONORARY OFFICIALS OF THE BRITISH SUNDIAL SOCIETY



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NOTE: Useful addresses and telephone numbers are listed on the back cover of this issue.

# DIALOGUE - NEWS ITEMS

## B.S.S. PRESIDENT

The British Sundial Society Council is pleased to announce that Sir Francis Graham-Smith F.R.S., who has recently retired from the post of Astronomer Royal, has accepted the invitation from the Council to fill the office of President of the British Sundial Society. Sir Francis was responsible for the initiation of the Jodrell Bank dialling project in conjunction with the B.S.S.

## B.S.S. VICE-PRESIDENT

The British Sundial Society Council is pleased to announce the appointment of Dr Marinus Hagen as a Vice-President of the British Sundial Society. His great contribution to dialling on the Continent and his founding of the Dutch Society are well known, and with his acceptance a link has been forged between the two largest dialling groups in the world.

## BRITISH SUNDIAL SOCIETY COUNCIL MEETING

A meeting of the BSS Council was held at the Parish Hall, Crowthorne, Berkshire [near Sandhurst], 10th November, 1990 commencing at 10.30 am. The agenda was crowded and only the briefest details can be recorded here. All the Council members were present.

Mr. Christopher St. J.H. Daniel was elected unanimously as Chairman, his first action was to call for one minutes' silence in Andrew Somerville's memory.

Mr. David A. Young was elected Secretary, Mrs. Anne Somerville was co-opted to the Council by unanimous consent.

Charles Aked proposed that the Astronomer Royal, Sir Francis Graham-Smith, be invited to fill the vacant post of President of the British Sundial Society. The Chairman proposed a second Vice-President, Dr. M. Hagen of the Netherlands, and this was agreed.

The Secretary proposed a working party for the restoration of sundials, this is to be further debated.

The Andrew Somerville Memorial Fund was officially approved and the donations received to that time - £135.50 - were transferred to the Fund.

The Editor reported on the *Bulletin* and informed the meeting that he would like to issue four Bulletins a year, the extra cost, to include the latest postage increases also, was about £3.00.

Details of the progress of the Edinburgh Conference were discussed, about half the places are already booked. A joint meeting with the Netherlands Zonnewijzerkring was discussed, also a September 1991 meeting in Cambridge, of 2-4 days duration. One of our members, Dr. Margaret Stanier, will help in this.

Mrs. Janet Thorne reported on the steady increase of membership, standing at 314 plus spouses, honorary and non-paying recipents of the *Bulletin*, total about 380. She proposed a plastic membership card instead of the present cardboard.

Mr. Taylor reported on Sundial Recording and the formation of an Advisory Panel. He mentioned the difficulties in transferring data sheets to computer records. David Young considered that the total dial records would be about ten thousand for Great Britain.

Mrs. Jane Walker gave details of the activities of the Education Group, the information pack produced had been requested by Jodrell Bank and the Science Museum, London.

David Young proposed an Andrew Somerville Annual Memorial Lecture to be given annually by an invited speaker. The possibility of a dial erected at Jodrell Bank to Andrew is under discussion.

Anne Somerville reported on the Jodrell Bank Project which has been approved by the Council as an official project. David Young is to form a Jodrell Bank Committee. Fuller details of this to be published later, but negotiations with the Jodrell Bank management have proceeded smoothly and the foundations have been laid for future progress. This will be an important part of the BSS contribution to dialling in Great Britain.

The Chairman ended the meeting precisely at 13.00, the time laid down by the programme, an excellent performance in view of the crowded agenda.

The next Council meeting will be held at Greenwich, the provisional date is 16th February 1991, to be followed by an afternoon local meeting.

*Charles Aked*

## BULLETIN OF THE SCIENTIFIC INSTRUMENT SOCIETY

Issue No.27 of the SIS *Bulletin* includes a mention by its Editor on page 1 of the Habermal sundial sold recently for £156,000. Whilst this seems a staggering sum, it merely reflects the sad deterioration in the real value of money. However the main centre-piece of interest to diallists is the article by Dr Allan A Mills entitled "The SIS Sundial; A Novel Adjustable Diptych Dial", with two full-page patterns for constructing an example, which the BSS editor did on receipt for his three-year old grandson, who expressed his delight on being given it [a future member?]. Dr Mills writes of the tilting of the dial so that it can be corrected for latitude from the place it was intended for use as being of recent recognition; yet BSS *Bulletin* 90.2 page 14-17 mentions the latitude tilting adjustment for the *Aï Khanoum* dial dated between 325 and 145 B.C. Too much correction and the dial does not look "right". The present editor found it was necessary to add strengthening pieces to make the completed dial robust, but a nice design and thought for the Christmas season.

The SIS *Bulletin* is recommended to all those with an interest in scientific instruments, there are four issues a year, the subscription £20.00 compares very favourably with the BSS. The joining fee of £10.00 must deter many but is waived for students, the conditions for being a student are not mentioned. The SIS *Bulletin* also carries five pages of advertising [six if anyone ever pays the £250 required for the back cover], and so has about the same amount of editorial text as the BSS *Bulletin.* Details of membership from Mr Howard Dawes, Executive Secretary SIS, PO. Box 15, Pershore, Worcestershire, WR10 2RD.

## L'ASTRONOMIE

The May 1990 issue [Volume 104] contains a most important article written by four people in collaboration [Pages 105-214] on the meridians in the church of Saint-Sulpice in Paris. These are actually scientific instruments on the grand scale combined with true art and represent the great class of interior noon sundials. They are, sadly, a mainly Continental concept although one may be found in Durham Cathedral on a more modest scale. The meridians are well worthy of study as they are fascinating from a point of history and the people who designed and constructed them, plus the ecclesiastical connections. The Church was the first Keeper of Community Time.

The Editor has written to Denis Savoie, President du Commission Cadrans Solaires and has received permission to publish this article in the BSS *Bulletin*. All he has to do now is to translate it from the French text with the help of his well-thumbed dictionaries. It will have to appear in four or five instalments because of its length, just another treat-to-be for the gnomonist readers of this journal.

We are struggling with the recording of British sundials, so the offer of two discs cataloguing over 189 MILLION heavenly bodies on page 239 should put our earthly problems into perspective.

In *Observations & Travaux* [Observations and Work], the journal of the Société Astronomique de France, similar in format and content to the previous journal; are some interesting articles by Denis Savoie and Robert Sagot [No's 16, 17 and 18 of 1989]. These are well worthy of future publication in our *Bulletin*, mentioned here because they have only recently come into the Editor's hands. But for his untimely death, they would have been translated by Andrew Somerville.

## DE ZONNEWIJERKRING

The September issue opens with an account of the weekend tour of the Arbietskries Sonnenhuhren 24-26 May 1990 and the Summer excursion of the Society in Holland 23 June 1990. A memoriam to Andrew Somerville is given by Dr Hagen, also to Dipl. Ing Walter Elsner who died 6 June 1990. A one-page account is given of the sundials in the clock museum at Schoonhoven [on page 44 is an illustration of the souvenir cardboard sundial]. Next a long article on Right Ascension and Declination by Dr Hagen, with a very short piece on hour-circles and declination circles. Fer de Vries deals with the problem of delineating the hour lines on inclining and declining dial faces - with reference to George Higgs and Leonard Digges, Jan Kragten contributes a short article on Nuremburg Hours, and a longer one on the declination of the sun, plus another on the terminator on a spherical body. A photograph of Archbishop Runcie by a sundial is shown page 35, followed by the usual book reviews filling several pages. The BSS *Bulletin* gets a good airing. The prolific Dr Hagen continues his description of sundials in The Netherlands, then two pages of tables for the declination of the sun for the year 1991.

On receiving these bulletins the Editor is reminded of his slothfulness in learning languages in his youth under the misguided belief they would never be of the slightest use to him. The material in *De Zonnewijzerkring* is first class but out of reach of those without a smattering of Dutch. No doubt in the future some of these excellent articles will be made available in English to readers of the BSS *Bulletin.*

## NEW SCIENTIST

### A DIFFERENT ANGLE ON THE TIME

A sundial which functions by holography has been devised by Kristina Johnson and Rob Penland at the University of Colorado in Boulder. A photographic image using a laser set at the required sun angle is made of each hour number, the plate is then mounted so that when exposed to sunlight, the image of the correct hour number is reconstructed, these of course changing with the apparent motion of the sun in the heavens. As holograms have a limited angular resolution of approximately 10°, and the sun moves only 15° an hour, it is not possible to record minutes. However by means of two divisional dots between the hour numbers, time can be indicated to a resolution of about twenty minutes of time. Kristina Johnson makes an advantage of this by claiming that the sundial is insensitive to latitude and seasonal variations, what it amounts to is that the design is too insensitive to indicate these. But an interesting version can be made to show different coloured hour numbers as the seasons vary.

If such a device could be combined with means of locating the north-south meridian [say using the polarization of the sun's light], we would be equipped with a sundial compass eminently suitable for the traveller. Perhaps it could be combined with some plastic payment card for true portability, and serve as a constant reminder that "Time is Money".

Thanks to Fiona Vincent for drawing the Editor's attention to this item in the *New Scientist* of 10 November 1990, page 28. Please note it is not a verbatim extract. Is there no end to the depth of penetration of the current interest in the art of dialling, and the casting of a new light on an old subject?

## THE DAILY TELEGRAPH

The 20 October 1990 edition contained an obituary [page 15] to Colonel Sir Edward Malet who died aged 82, together with a mention of the invention of the "Sun Compass" described in the article "Lambert's Circles" by René R.-J. Rohr in BSS *Bulletin* 89.1. pp 9-14. The part played by Malet - "made a valuable contribution through his part in the invention of the sun Compass", is not known to the Editor. Does any member know the details? Possibly his contribution was his test sorties navigating deep into the heart of the Sahara desert, using the instrument devised in America J.M.S. Kaufman and Shelley Krasnow, USA, Patent No. 2,411,636 of 18 May 1948.

# MAKING A START - THE EQUATION OF TIME

BY DAVID YOUNG

In the last issue I described how to mark out the hour lines of a simple south facing dial. This dial like most (but not all) dials will tell you the correct local time and for centuries this was just what was wanted because everyone used this time. Nowadays we use Greenwich Mean Time (and add an hour on in the summer). In order to convert our sundial to read GMT there are two adjustments to be made (1) to allow for the longitude of your location (ie. how far East or West you are from Greenwich. (2) to allow for the Equation of Time.

I will deal with this second adjustment now, so if you know all about it then skip the following and proceed to the next article! If however the Equation of Time seems to you as something to do with long ago school algebra lessons, then do read on - you will have a pleasant surprise for it is not, and it's all much simpler than you think.

People always used to assume that the sun moves across the sky at a constant speed (most people still do!), and therefore that the interval between one 'noon' and the next 'noon' was exactly the same, ie. '24 hours'. However when the early mechanical clocks became more accurate it was found that this was not so and that there was a small variation at different times of the year. As it was sensible to have hours of constant duration and as it was not practical to make clocks that went fast or slow at different times of the year, a scheme was devised to average out the length of the day throughout the year and the resultant time was called 'mean' time.

It was discovered that this variation of the sun's passage across the sky was due to two separate causes. The first is due to the tilt of 23½ degrees of the axis of the earth, which causes a variation shown in the graph figure 1. The second variation is due to the fact that the earth's orbit around the sun is not circular but elliptical, and at times in the year when the earth is nearer the sun it moves faster, this variation is shown in the graph (figure 2). Although both graphs are symmetrical you will notice that the peaks and troughs occur in different months so that the combined effect produces a rather unusual shaped graph as shown in figure 3. This graph then shows us the difference between clock time (or mean time) and local time (sundial time) and this relationship is known as the 'Equation of Time'.

It should be noticed that on four days in the year the times are identical, at other dates you will need to add or subtract the number of minutes indicated to convert from sundial time to clock time or visa versa. More accuracy can be obtained if you use a table giving the exact variation on each day of the year, these can generally be found in most books on sundials but I can send anyone a copy if they would like to send me a stamped addressed envelope. The other adjustment to allow for your distance from the Greenwich meridian will be in the next issue.

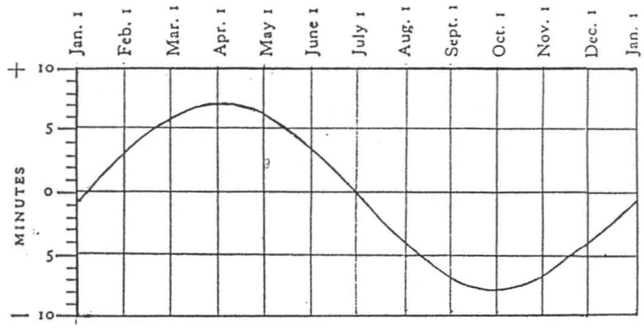



Figure 1
Variation from mean time due to tilt in earth's axis

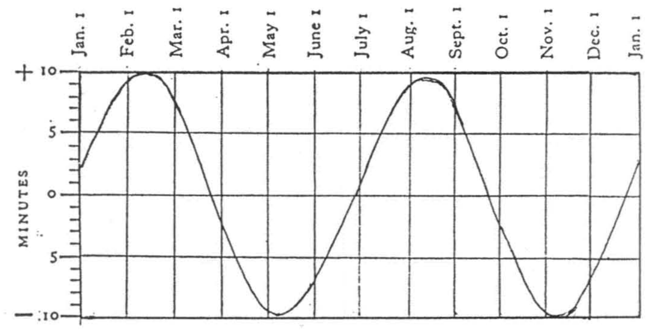



Figure 2
Variation from mean time through ellipicity of orbit of earth

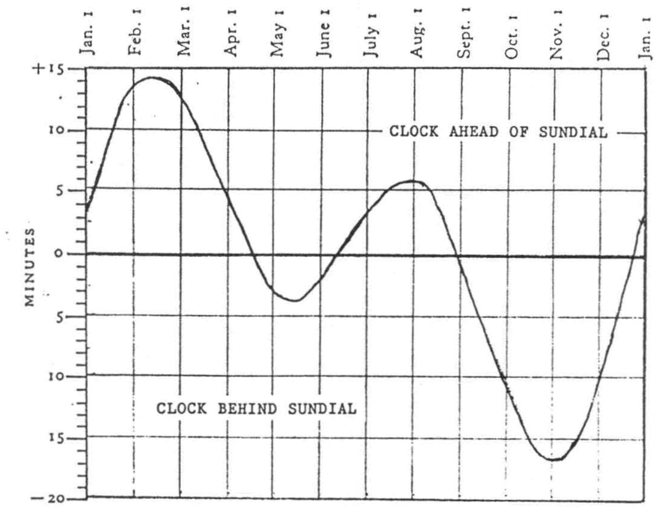



Figure 3
Resultant total variation between solar and mean time - 'Equation of Time'

## EDITOR'S NOTE

There is also an annual change because the year does not contain a whole number of days, correction by a leap day is necessary every four years to take account of the quarter days.

See also Colonel McVean's article containing the Equation of Time. This is presented in the inverse form- 'Sun Fast - Sun Slow' on Mean Solar Time.

# THE HAMPTON COURT DIAL OF JOHN MARR, 1631 (Part 2)
## A. R. SOMERVILLE

18 The description of the circles wch are uppon the Horizon (or margent) of the Horizontal concave.

The bredth of this margent is divided into 3 severall partes, the first and outtermost of them hath the circumference thereof divided into the 12 months of ye yeare, and the bredth of it divided into 4 spaces. The outtermost of wch spaces, hath written in it the names of the monthes, and the Saints days. The holidaies are written in redd letters, and the common saints daies in black. The second space hath onlie the numbers for the daies of each moneth.

And the third space hath the single graduation for the daie of each moneth, with the Dominicall letters written uppon them.

The fourth space is onely a circle of gould
19 graduated according to the daies of the moneth, wch hath a certeine Arithmeticall nomber written uppon most parte of the divisions thereof wch is the Prime or goulden nomber, whose use is to find the change of the moone as shall be showed hereafter.

The second parte of this margent is divided (in the circumference thereof) into the 12 signes of the Zodiack and the bredth thereof into three spaces.

The innermost of wch spaces hath onelie ye name of the signes and ye midmost the nombers of their degrees and the third and outermost (wch is next unto the daies of the moneth) the graduations of theire single degrees.

The third and innermost parte of this margent (the whole circumference thereof) is divided into 32
20 equall partes, resembling the 32 windes, or Rhumbs or points of the mariners compass. And amongst theire points towards the east and west (upper circular segments of gould) are graduated (though unequallie) the 12 moneths of the yeare and their daies, for from the intersection of the Tropique of Capricorn ♑ with the Horizon neere the Northwest, unto the intersection of the Tropique of Cancer ♋ with the Horizon neere the Southwest there is sett downe all the months and daies from the sunnes enterance into Capricorn ♑ , untill his entrance into Cancer ♋ according to the sunnes amplitude for everie daie. And in like manner on the East side from the Tropique of Cancer ♋ to the Tropique of Capricorn are sett down (as before) all the moneths and daies from the sunns entrance into ♋ untill his entrance into ♑ .

There is likewise belonging to this margent, a
21 certeine Table wch is written uppon ye North Diall plaine and it consisteth of 3 columnes. The first is the yeare of our Lord from 1631 untill 1660. The second is the Dominicall letters proper to each of those yeeres. And the third is the Prime or Goulden nomber. And thus much for the description of ye Horizontall concave and his margent.

The uses of theise lines and circles are manie and diverse, but at this time we shall onlie [reflect?] uppon some few of them wch shalbee most pertinent to our present purpose for the use of this Diall.

### TO FIND THE DAIE OF THE MONETH WHEREON ANIE FESTIVALL OR SAINTS DAIE SHALL FALL THAT IS NOT MOVEABLE

The festivall and saints daies are [heowe] set uppon the margent right against the daie of the moneth whereon they fall, so the feast of St John the Baptist is set against the 24 of June and the feast of St. Michael the Archangel against ye nine and
22 twentieth of September. And soe of anie other standing festivall.

### TO FIND WHAT DAIE OF THE WEEKE ANIE DAIE OF ANIE MONETH SHALL FALL UPON.

First finde (in the second Collomne of the Table uppon the North Diall plaine) the Dominicall letter of that yeere, and against what date of the moneth soever (throweout the whole yeere) you shall finde that letter, the same daie shall be Sundaie, and the next day after mundaie etc.

Example

The yeere, 1631 B is the Dominicall letter, therefore throughout the whole yeere B shallbee Sundaie, C munday D Tuesdaie E Wednesdaie etc. But whensoever you shall finde two Dominicall letters (wch is everie leape yeere) so 1632 AG, the first of them A shall serve from the first of Januarie
23 till the first of Marche and the other to the end of the yeere. Noate alwaies the Dominicall letter and Goulden nomber doe change the first of Januarie.

### THE YEERE OF OUR LORD BEING PROPOSED, TO KNOWE WHAT DAY OF ANIE MONETH IN THAT YEERE THE MOONE SHALL CHANGE.

ffirst find the goulden nomber for the yeere proposed in the third collomne of the table uppon the North Diall plaine, then find the same goulden nomber in the margent (in the goulden circle that goeth round in the middst thereof) against the moneth, wherein you desire to know the moones change, and the daie of the moneth against wch that nomber standeth is the daie of the change for that yeere.

Example

24 December 1631 is desired to knowe the daie of the moones change. The goulden nomber for the yeere we finde to bee 17, and in the goulden circle uppon the margent we finde 17 to stand against the 13 daie of December wch is the daie of the change.

And soe in Maie 1645 finding 12 to bee the goulden nomber you shall find it in ye goulden circle aforesaid to stand against the 15 daie of the moneth wch is the daie of the change for that yeere and moneth.

The howre and minute of the change might have been added, together wth the Eclipses of ye sunne and moone, but that ye narrowness of the margent would not admitt it, yet nevertheless of so havinge the daie of ye change you may easilie knowe the age of ye moone.

25 **AND SOE KNOWEING HOW TO FINDE THE DAIE OF THE WEEKE AND THE DAIE OF THE MOONES CHANGE, TO FIND ANY MOVEABLE FEAST ALSO.**

To show ye reason why theise feasts doe fall early or late in the yeare in this place weare noe waies convenient, onlie it shalbee sufficient at this time, to showe how to finde them, wch shalbee brieflie thus.

The first Tuesdaie after ye change in fibruarie, shalbee Shrovetuesdaie, the Sundaie before shalbee Shrove sunday and the seventh sundaie after that, shalbee Easter, and the seventh after Easter shalbee Whitsonedaie. the thursdaie seavennight before Whitsundaie shalbee asscension daie, and that sundaie after it is Trinitie, and ye thursday after Trinitie shalbee [Corpus] Christi daie etc.

26 **THE AGE OF THE MOON BEING KNOWN TO FIND THE TIME OF HER COMING TO THE SOUTH AND THE HOWRE OF HIGH WATER AT LONDON BRIDGE.**

There is uppon the margent of the North direct concave three severall circles described, the outermost of wch is divided into 29 1/2 wch is ye whole age of the Moone, for the time from one change to another is 29 daies and a halfe.

The nombers of the middle circle showeth unto us the time of her coming to the south everie daie of her age against wch they stand. As the sixt daie of her age standeth a little before 5 and the seventh daie a little before 9.

The innermost circle sheweth the hower of high water at London bridge, everie daie of the age. As the sixt daie of her age it wilbee high water a little before 8 and the seaventh, a little before 12.

27 **THE DAIE OF THE MONETH BEING KNOWNE TO FIND THE PLACE OF THE SUNNE AND CONTRARIWISE.**

The place of ye Sonne in the margent is sett right against the daie of the moneth, as against the 16 day of Januarie there is the sixth degree and a halfe of Aquarius ♒ And against the 24th of June the twelth degree and tenn minutes of Cancer ♋ , And soe oberving the contrarie waie in havinge the place of the Sunne knowne you may easilie finde the daie of the moneth.

**TO SHEWE THE HOWER AND MINUTE OF THE DAIE BY THE SHADOWE OF THE STILE.**

The hower of the daie may bee seene uppon everie diall of this stone, but first wee will beginn with the Horizontall concave, And therefore (when
28 ye sunne shineth) observe wheare the shadowe of that edge of the stile falleth wch inclineth to the North, and the meridian or hower line passing by that place will shewe the hower and minute required, providing that you remember what hath been said alreadie, that the distance between every of theise hower lines maketh 4 minnuts of time.

**TO SHEWE THE HOWER OF SUNNE RISING OR SETTING BY THE SHADDOWE OF THE STILE AND CONSEQUENTLY THE LENGTH OF YE DAIE AND NIGHT.**

Observe amongst the parallels of declination wheare ye shadowe of the pointe of the stile falleth and followe that parallel to ye Horizon at ye west, and the howerline passinge by that intersection, shall shewe ye hower of Sunn risinge, and followe ye same parallel to ye Horizon at the east, and ye howerline passing by that intersection shall shewe the hower of Sunne sett, which hower of Sunnsett
29 being doubled maketh ye length of the date and hower of sunnrisinge being doubled, maketh ye length of the night.

Noate, that if the shadowe of the point aforesaid doe not fall exactlie upon one of the actuall parallells, yett marke how neere it falleth to anie of them, and with yr eye followe that distance alonge to the Horizon at East and west, as if an actuall parallell did passe by that pointe. And further noate that Wheresoever the shaddowe of this pointe falleth, the immaginarie parallell passinge thereby shall hereafter bee called the Parallel of ye Pointe.

**TO SHEWE THE PLACE OF THE SUNNE BY YE SHADDOWE OF YE STILE.**

Observe where ye Parallel of the Point will cutt that quadrant of the Ecliptique that answereth for
30 ye seasoun of the yeare when you desire to knowe ye Sunns place and that point of the Ecliptique soe cutt by the Parallell, shalbe the place of ye Sunn required And if you bee not mistaken in this observation, looke uppon the greater moneth described in the margent, and against ye same daie of the moneth you shall find the place of ye sunne as before.

**TO FIND YE RIGHT ASCENSION OF THE SUNNE BY YE SHADDOWE OF THE STILE.**

Ffirst, by ye last proposition finde ye place of ye sunne in ye Ecliptique and looke what howerline passeth by ye thereof followe it unto the Equinoctiall, and the nomber at the Equinoctiall shall answere your desire. But ye nomber of ye whole howers maybee readilie knowne by the white numerall letters neere the Arctique circle, and ye odd minutes by ye Equinoctiall, ffor if the place of the sunne bee in ye first quadrant of ye Ecliptique
31 there is the right ascension lesse then in howers and if it bee in the second quadrant it is betweene six and 12 howers, And if it bee in the third quadrant betweene 12 and 18 howers. And in ye fourth quadrant betweene 18 and 24 howers.

Likewise if it bee demanded to knowe ye right ascension of anie point of the Ecliptique, followe the howerline passinge by that pointe (as before) wch shall answeare your desire.

(To be continued)

# A CROSS DIAL FOR A SCOT
## (IN MEMORY OF ANDREW SOMERVILLE)

The basic element of the well known Cross or Star dials may be described as the equatorial notch. This consists of two flat surfaces built from or cut into solid material, both parallel to the earth's polar axis (ie perpendicular to the equator) and so described as 'polar planes'. These surfaces meet at an inner straight edge which is likewise parallel to the polar axis. Either flat surface may serve as the reception surface for the shadow of the opposite outer edge of the notch, which is cut parallel to the inner edge and so, again, parallel to the axis. Each outer edge serves for an appropriate period as an ordinary line gnomon. Any point on such an edge, and in particular its termination at a corner, may serve as a nodus or point gnomon to indicate the sun's declination. The lines of equal declination on any polar plane are sections of parabolae.

The first sketch shows a notch, open at the top for clarity and closed at the base, with a typical shadow such as might be cast in a south facing notch around five o'clock local solar time on a summer afternoon.

Such notches are familiar, cut into suitable faces of multiple dials, in which case the ends of the notch are usually closed by planes perpendicular to the edges and so parallel to the equator. Such an end plate may serve as an equatorial dial with hour lines at 15° intervals. The hour lines on the polar faces just continue these in the polar direction.

The second illustration shows a winter afternoon shadow in a notch cut into a south facing polar plane. Each face of a symmetrical right angled notch subtends 45° at the opposite edge and so will record the lapse of three hours. Cross dials are often made with their upper notches in this form. The Star of David, or star hexagon, records only two hours on each of its twelve faces. One such is illustrated here in equatorial section.

An equilateral notch will record four hours lapsed time on each of its faces. A St. Andrew's Cross with alternative angles of 60° and 120°, and its narrow axis in the meridian plane will then, as shown in the section, record the morning and afternoon hours fairly evenly, with an expanded section around midday. The cross must be made deep enough along the polar direction for the shadow still to fall on the back edge at solstitial noon, so the least depth will be L tan $23\frac{1}{2}$°, where L is the length of the cross. If we wish to furnish declination lines so that these do not cross even at their solstitial limits, twice the depth is required. The vertices of the parabolic declination lines lie on the 4 o'clock and 8 o'clock hour lines, where the shadow plane falls perpendicular to the receiving plane. In view of the expansion of the scale near noon, it would be easy to furnish a [divided] analemma round the noon lines.

Since each notch functions as a dial, the thickness of solid material may be chosen simply for durability and appearance. In a wooden model, I have screwed the cross to an equatorial base board simply for the sake of rigidity. Stone ought generally to look as well as be solid, but metal would permit a strong and slim construction with, for example, the cross mounted on a central polar rod.

The design of multiple notch dials more complex than the simple cross offers much scope for ingenuity. To avoid blank periods, we must ensure that the indicating shadow plane enters one notch at least immediately it vacates another. This is most simply ensured by pairing notches on parallel opposing faces of the structure, but there are plenty of other possibilities.

*George Wyllie*

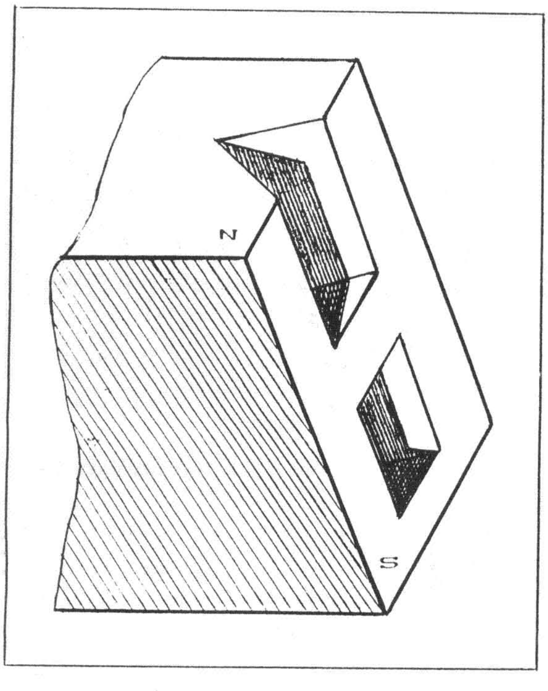



FIG 1 - Equatorial notch and shadow at 5 p.m.

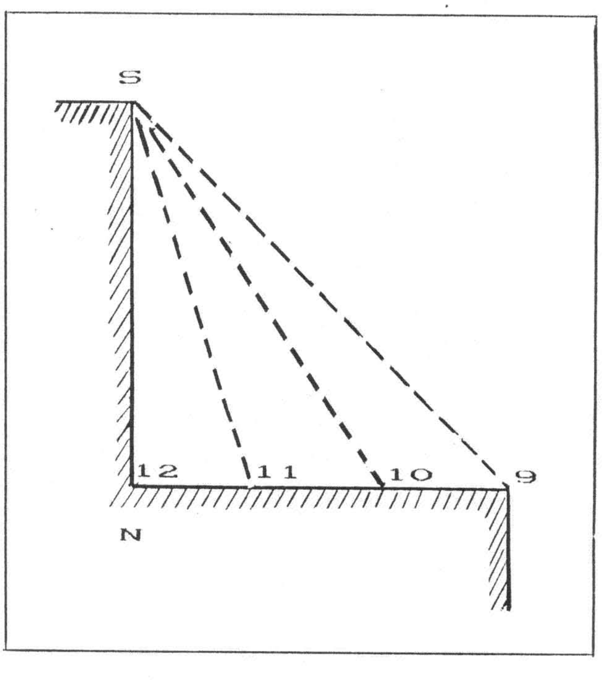



FIG 2 - South-facing polar plane notch

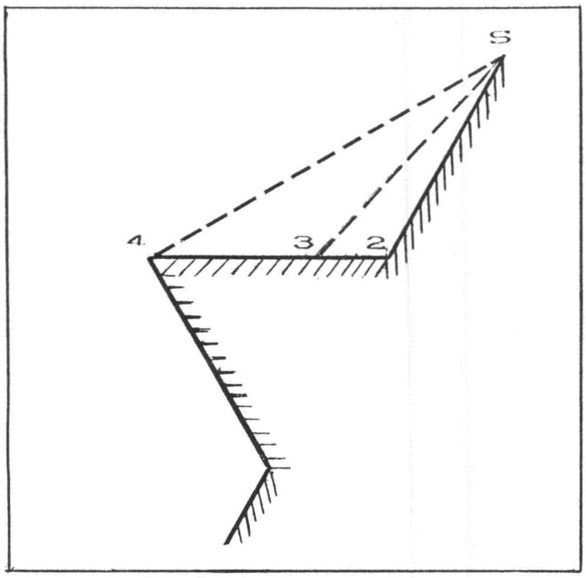



FIG 3 - Star of David or Star Hexagon Dial

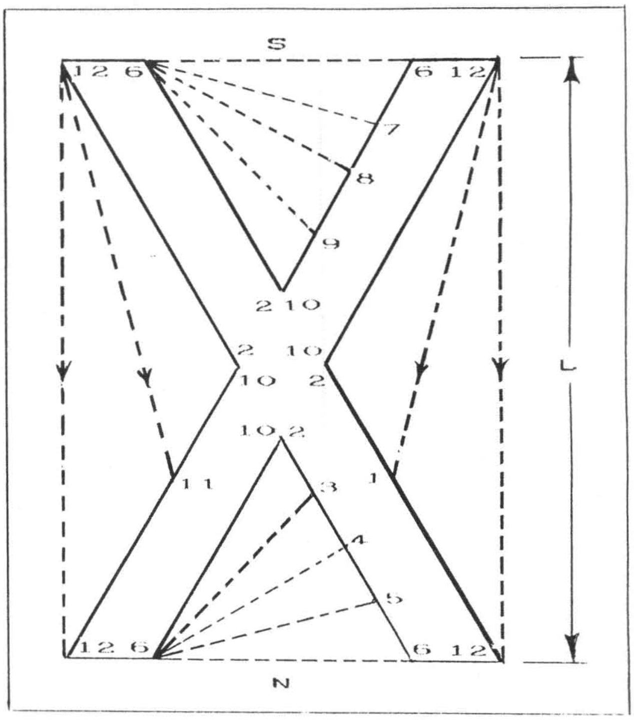
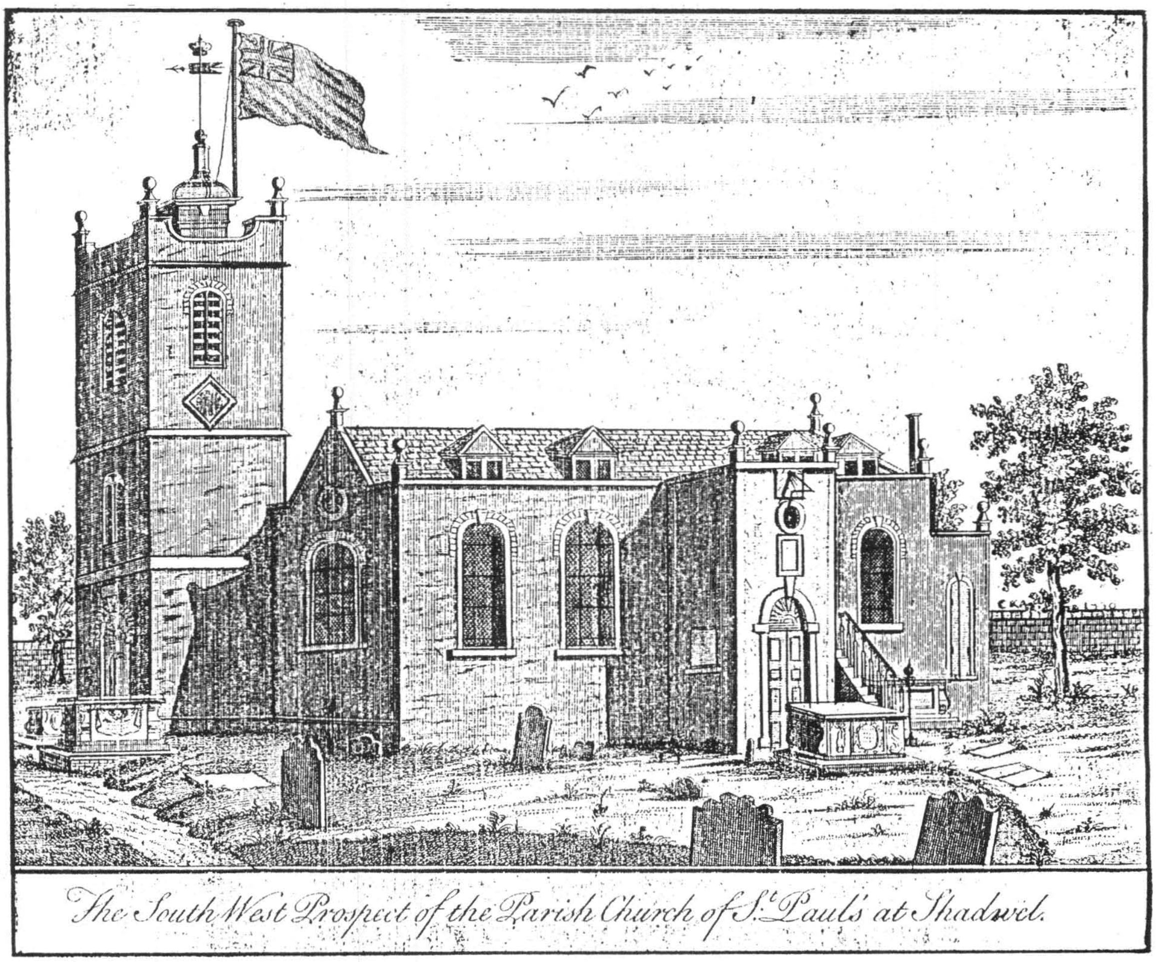



FIG 4 - St. Andrews Cross Dial




The Editor has had this engraving for years. Does anyone know if the sundial still exists?

# THE ROMAN CYLINDRICAL SUNDIAL IN THE ZEMALJSKI MUSEUM, SARAJEVO, YUGOSLAVIA

MILUTIN TADIC

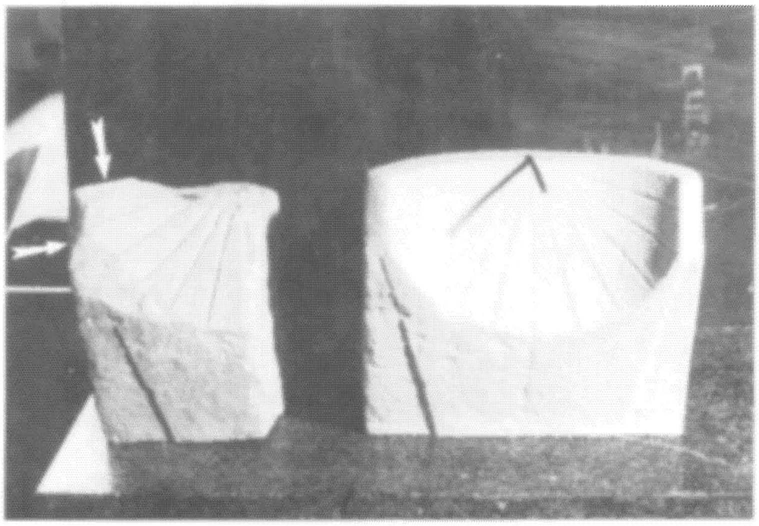


FIG 1
Fragment of Roman cylindrical sundial from "Zemaljski museum" in Sarajevo, and its reconstruction, made by academic sculptor Stjepo Gavrić.

At a basic level, Greek and Roman sundials possess some features in common, both types being carved in stone with divisions not usually at less than at one seasonal hour intervals. The gnomons were not placed on the axis of the celestial sphere [this would have given shadow indications inappropriate to the time system of the age], and these gnomons have rarely survived to the present day. Although planar dials existed (horizontal, vertical and multiple facetted also), the concave dial surface which received the shadow of the gnomon at all times of the day, whilst the sun shone, prevailed. The classic sundial of the Ancients still remains unexcelled in its functional and artistic simplicity to this day. In her dissertation, Sharon L Gibbs [*Greek and Roman Sundials,* 1972], describes 280 sundials; since it was published the number has, of course, increased with more recent discoveries. Amongst this listing the conical and spherical forms predominate in almost equal numbers, followed by a much smaller number of planar dials, and finally the cylindrical dials, a mere six of them. Amongst the eleven dials of antiquity discovered up to now in Yugoslavia, only one example is of cylindrical form, and although found almost a century ago, it has not been made available to the public so far, it is in the "Zemalijski Museum" reserve store in Sarajevo [Inventory No. 327].

This sundial was brought to Sarajevo from Stolac in 1894 [Latitude 43° 05$^1$, Longitude 17° 58$^1$], from the remains of the Roman settlement *Diluntum* [approximately I-VI centuries AD]. In actuality it is the west half of the limestone sundial broken along its meridian line [see Fig 1 left]. The rear section of the dial is hemispherically rounded, the fragment remaining is 275 mm in height, by about 180 x 145 mm, on which the seasonal hour indications are preserved to different amounts. These lines cut off arcs on the front edge of 44-45 mm, no day curves are cut into the dial. Only the rusty trace of the horizontal gnomon is now visible at the origin of the "hour lines". The concave dial face is part of an imaginary circular cylinder surface whose axis is inclined to the horizon, being most effective when this axis coincides with that of the celestial sphere, as shown on Fig 2.

This figure illustrates the meridian section through a cylindrical sundial for a latitude of 43°. The horizontal gnomon N, is set in the apex plane, along the meridian of the site, its tip on the axis of the cylinder [the axis of the celestial sphere]. Through this point, diurnal arcs of the celestial equator and the tropics, as well as circular arcs, are centrally projected on to the cylindrical surface of the dial. The front edge of the dial is cut away along the Tropic of Cancer projection, and hour lines connect the twelve divisions of the day curves to give seasonal hours. The meridian line is part of the imaginary cylinder generatrix. If the lateral surface is developed into a plane, the inner gnomonic cylindrical projection is obtained, see Fig 2 [right], where the projection is of the west half of the dial surface: $N_1^1$ $E_2^1$ is the apex edge of the dial surface, $B^1O^1$, $A^1E_2^1$ are the projections of the diurnal arcs of the Equator, the Tropic of Capricorn and Tropic of Cancer respectively, the latter being the front edge of the sundial, $N_1^1$ $B^1$ is the position of the horizontal gnomon, $A^1C^1$ is the meridional direction; whilst the remaining hour lines are directions [as projections of great circle arcs] without common pole. For comparison purposes, the projection of the hour circles of the celestial sphere are drawn every 15° and shown below as 12, 3, 6, 9 hours, with the seasonal hours shown in Arabic figures along the line $C^1E_2^1$ 7, 8, . . . 11, 12 [$C^1$ being the end of the sixth hour of the day].

The inclination of the meridian line as generatrix of the cylindrical sundial construction described indicates the geographic latitude for which the sundial was constructed, whilst the inclination of the front plane is the complement of the latitude.

Most fortunately the remains of the dial have retained fragments of the original surfaces [marked by arrows of the photograph] and this has enabled a faithful reconstruction of the original form of the sundial to be amde by the academic sculptor Sjepo Gavric. The meridian section is represented in Fig 3, where the concave dial surface is a part of the lateral surface of an imaginary cylinder of radius 175 mm. The tip of the gnomon could not have been on the axis of the cylinder and was probably at point 0, the intersection of the apex

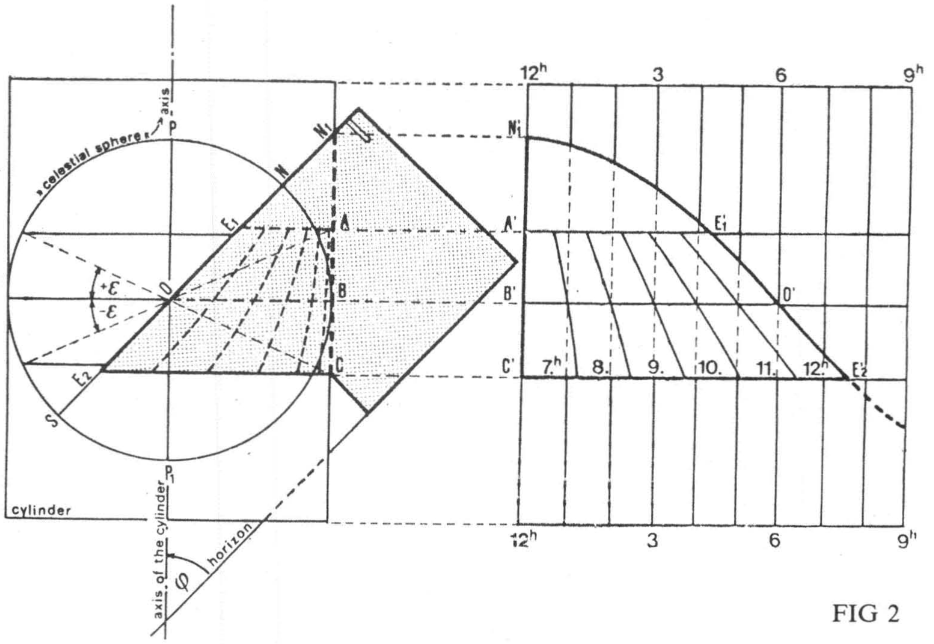



FIG 2

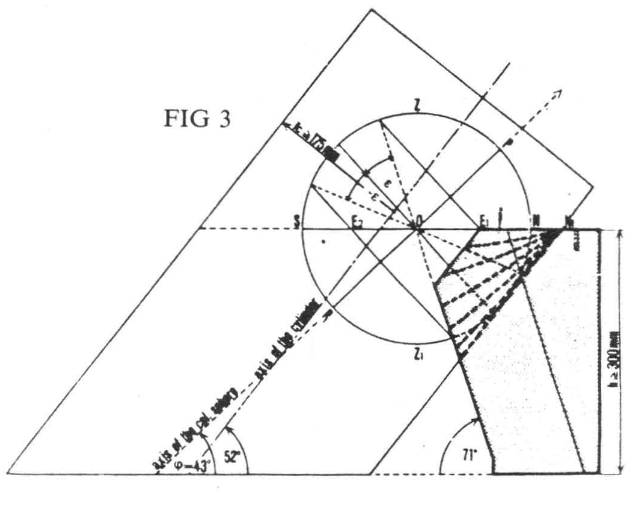
and frontal planes of the dial. In this position the dial surface would capture all the meridian shadows because the inclination of the frontal plane from the horizon [71°] is equal to the maximum meridian altitude of the sun at the geographic location of *Diluntum.* The inclination of the frontal plane and the inclination of the meridian line to the horizon [52°] clearly indicate that the dial is not based upon the theoretical model explained above.

In the present-day hour system, the hour circles have a common axis, that of the celestial sphere, in which we place the style, by this means the direction of the style's shadow indicates the equinoctial hours. The lines which connect the twelfth parts of the diurnal arcs of the simulated sun's path on the celestial sphere, are also arcs of great circles but these have neither a common axis, nor pole. Therefore, on ancient sundials, they are confined within the projections of the celestial tropics, and the gnomon shadow cuts them and indicates the seasonal hour by its tip.

This would have been so if the *Diluntum* dial had been constructed on correct dialling principles. But at this period dials were being constructed which were not in accordance with the strict rules of correct dialling: plane or concave faces were simply divided into twelve approximately equal parts and the gnomon set up in their centre. The shadow of the gnomon did not cut the hour lines as projections of the horary arcs of the celestial sphere [as may be seen from the photograph], resulting in a division of the day differing slightly from the formal seasonal hour system.

**Editor's Note:** This article was the last which Andrew Somerville rewrote and he expressed his lack of satisfaction with the resulting text. I have re-edited it again and was more than pleased to find my wording similar to a further revised version made by Andrew and sent to Mr. Tadic, which I received later. However I am not entirely happy with the result, so members must bear this in mind before blasting me with their criticisms. The division of the day into hours not exactly conforming to the correct division of one-twelfths of the day would not of itself make the slightest difference in practice if everyone was making use of the same time standard. I

FIG 3




cannot see how the indication could be other than by the gnomon tip, since the division of the day into twelfths, even at its most approximate, cannot be achieved otherwise. The tip of the gnomon, normally placed on the axis of the celestial sphere, is the only point to remain correct during the annual excursions of the sun for purposes of division of the diurnal sunlit period into one-twelfths. In this present case it should therefore also be on the axis of the cylinder for correct indication.

Often the "hour lines" were continued beyond the Tropic of Capricorn [and occasionally slightly beyond the Tropic of Cancer] but have no significance since the shadow of the tip never enters these areas; and beyond the Tropic of Cancer in this example there is no dial surface for indication. It looked better to have the hour lines meeting at a common point, even if there was no common pole. Any errors here may be due to my misunderstanding of Mr Tadic's text.

*Transcribed 24th September, 1990*

# ALIGNING THE GNOMON

ALLAN A. MILLS

The essential condition common to almost all patterns of equal-hour sundial is that the gnomon should point at the celestial pole - ie. close to *Polaris*, the pole star. Once this alignment is correctly fixed, then the hour-indicating shadow cast by its operative edge (or stile) may be received upon *any* surface (curved or plane) in *any* orientation. The entire dial may also be rotated around the stile to give a direct-reading compensation for longitude or Summer Time. The reason we commonly see cylindrical surfaces (in armillary and ring designs) or horizontal and vertical planes (in 'pedestal' and 'wall' dials respectively) is simply one of convenience in calibrating these comparatively straight forward projections.

The usual textbook statement that a sundial must be constructed to suit its location is therefore rather misleading: a horizontal dial correctly designed for, say, 50° N may be transferred to 60° N and will still work perfectly provided a wedge is inserted beneath its base so that the *entire dial* is inclined upwards at 10°, making the gnomon point at the new 60° altitude of the pole star. In the same way, a 90° diptych card may be used anywhere within a range of latitudes by simply trimming its base to adjust the slope of the entire dial[1].

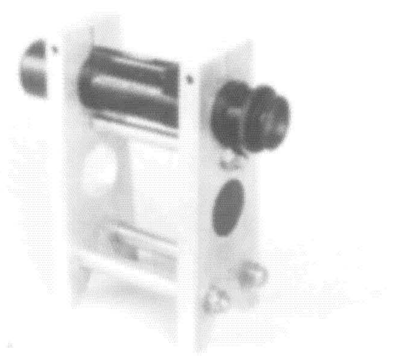
This 'Theorem of the Sundial' follows directly from the geometry of its operation, but not until the remarkably recent date of 1962 was it clearly defined by the astronomer R. d'E. Atkinson[2]. The principle was subsequently made known to a wider readership by mentions in the well-known practical texts by Cousins[3] and Waugh[4]. It is inherent in the 'Universal' dials, and was undoubtedly known and used by some 18th and 19th century makers, but on the other hand we find traveller's diptych dials with alternative string-gnomon heights keyed to a range of corresponding dial patterns for various latitudes[5].

Alignment of the gnomon with the celestial pole is, then, the all-important setting. Many of the classic works on dialling do, however, obscure this fact by confining instructions on how to orient a dial to one of discovering the meridan by watching the shadow cast by a plumb-line or vertical post. With care, this procedure is effective, and certainly emphasises the intended solar relationships. However, many dials may be more quickly and accurately oriented by means of observations of the pole.

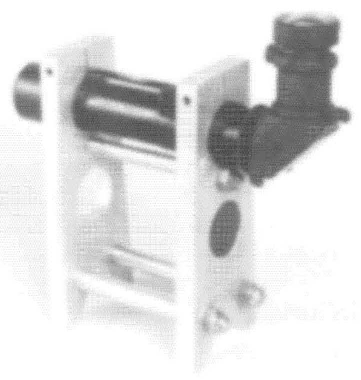
This may be accomplished with sufficient accuracy for most 'garden' dials by the use of a simple jig placed astride the gnomon. Two plywood vees are cut out simultaneously, a small hole drilled perpendicularly through both, and then the vees separated and held rigidly apart by a suitable block or spacers. Fix this device temporarily to the sloping gnomon (eg. with adhesive vinyl tape) and then adjust the entire dial until *Polaris* appears in the peep-holes. (This star may be readily indentified by reference to any star map or planisphere[6].)

A more sophisticated alignment device is shown in Figure 1.

Here the 'peep-sight' is represented by a central hole and target in the plastic inserts recessed within the identical aluminium legs. The approximate alignment may then be refined by viewing through the small 'gunsight' telescope,



adjusting the sundial until *Polaris* falls on the crosshairs[7]. A diagonal eyepiece (Fig. 2) will frequently prove convenient.



For really accurate alignment the 47 arcminutes displacement of *Polaris* from the celestial pole may be compensated by setting it on a circle of this angular radius inscribed around the crosshairs of the graticule. However, this extra refinement is more for setting-up astronomical telescopes than sundials.

## NOTES AND REFERENCES

1. A.A. Mills, 'A Novel Adjustment Diptych Dial', *Bulletin of the Scientific Instrument Society,* No.27, December 1990.
2. R. d'E. Atkinson, 'Forum', *Journal of the Institute of Navigation, 15* (1962), 454-455.
3. F.W. Cousins, *Sundials* (Baker, London, 1969). pp. 78-82.
4. A.E. Waugh, *Sundials: Their Theory and Construction* (Dover, New York, 1973).
5. P. Gouk, *The Ivory Sundials of Nuremberg, 1500-1700* (Whipple Museum, Cambridge, 1988).
6. For example, those published by George Philip & Son Ltd., London.
7. Previously check these are exactly on the optic axis by rotating the telescope in its loosened mounting whilst viewing a distant terrestrial object: the latter should remain centred on the crosshairs.

# ONE WAY OF LOOKING AT IT
# EQUATORIAL AND POLAR DIALS

At the beginning of the thirteenth century, one Abu Al Hussan divided the day into 24 hours. Before that, most sundials showed temporary hours, these being the length of the day divided into twelve equal periods. In summer when the days were longer, the hours too were naturally longer than in the winter when the days were much shorter. If you were paid by the hour, you would have had to work longer for your money in the summer, surely a matter for the unions. Pythagoras, the friend of schoolboys, divided the circle into 360 parts or degrees. These divisions give the two essential tools for measuring the daily progress of the sun in a meaningful way.

Suppose now that you are standing exactly at the North Pole [or South Pole] in the local summer, the sun would appear to circle around you once in every 24 hours. Divide 360° into 24 parts and you will find the sun travels throught 15° in one hour, or 1° in four minutes and 1/60 of a degree [one minute of arc] in 4 seconds. Reproduce this on a piece of card, either by drawng or photocopying a protractor, place a small upright pin in the cente, and you have made yourself an equatorial sundial which will tell the time anywhere on earth, provided that you align its plane parallel to the plane of the equator. You can do this by looking up your latitude on an Ordnance Map of your locality, where you will find the scale of Latitude on the right and left, and the Longitude on the top and bottom. Subtracting the Latitude from 90° will give you what is known as the Co-Latitude. Cut out a piece of card to include this angle and placing it vertical on a horizontal plane, use it to set up your dial scale with the 12 o'clock mark facing due South, see Fig 1. The shadow of the pin will fall on the Northern 12 mark when the sun is due South on your local meridian, and this is 12 midday by the sun, or noon, solar time.

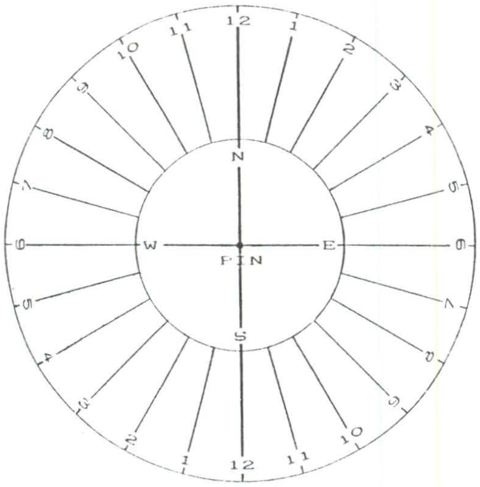



FIG 1: Divison of the Equatorial Dial

If you were to make the equatorial dial rotatable about its centre, you would be able to align this dial parallel to the Greenwich or any other chosen meridian. Suppose you live West of Greenwich on Longitude 15° West, you will perceive from Fig 5 that if you rotate your N/S line 15° anticlockwise, it will be parallel to the Greenwich meridian. As the rays of the sun are parallel, your dial should then indicate Greenwich Mean Time.

Now I have some bad news for you. The sun is not a good timekeeper and, like a naughty boy, needs constant attention if the indication on the dial is to give "clock time". The correction required is known as the Equation of Time and will be discussed later in this note.

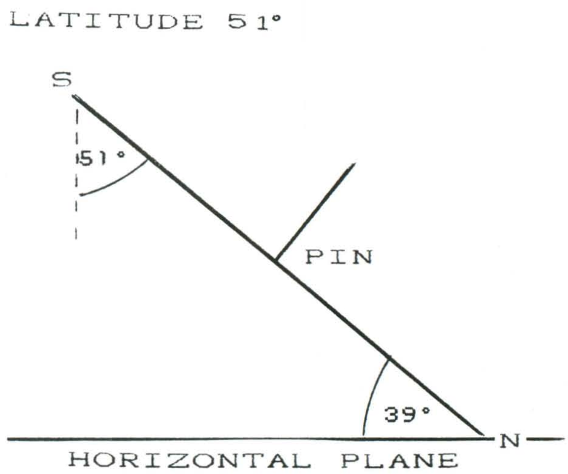



FIG 2: The orientation of the Equatorial Dial

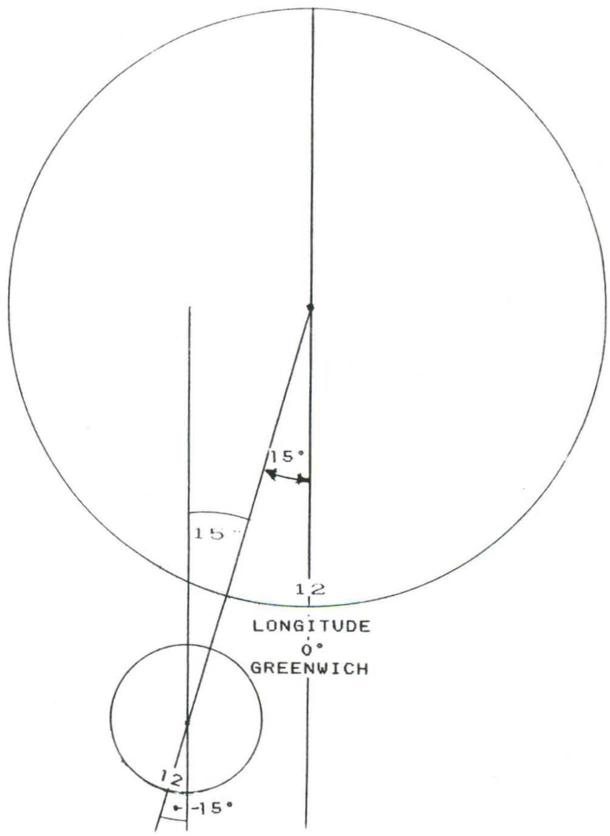



FIG 3: The Movement of the Sun Shadow

Having described the situation so far with admirable clarity, I now have to tell you that this dial will indicate only in summer, or strictly speaking between the spring and autumn equinoxes. Between the autumn and spring equinoxes the sun will shine under the dial, so you may extend the pin or gnomon below the plate and reproduce the numbers below. This makes the observation somewhat difficult in the winter period. I have tried a reflecting surface below the plane, but this is not particularly successful in practice. There is a simpler way to overcome this problem and that is to combine the dial with a polar dial.

If you place a rectangular plate with its plane parallel to the axis of the poles with a pin in its centre, the sun will appear to rotate about the pin at the rate of 15° an hour, and the shadow of the pin will move West to East as the sun apparently travels East to West, see Fig 3.

Looking at Fig 5, AB is the upper edge of a plate arranged so that its plane is parallel to the axis of the Poles and you are looking directly down on to its surface. CD is a pin projecting from its centre at right angles. The sun in its passage from East to West at 15° per hour will light the plane except where the pin throws its shadow on AB. It will be seen that there can be no shadow at 6am or 6pm, so it is usual to mark the hour marks on this type of dial from 7am to 5pm only.

To mark out the dial, produce DC through E to F, making CE and EF equal to DC. Describe an arc of 180° round point D and mark off in 15° segments, labelling

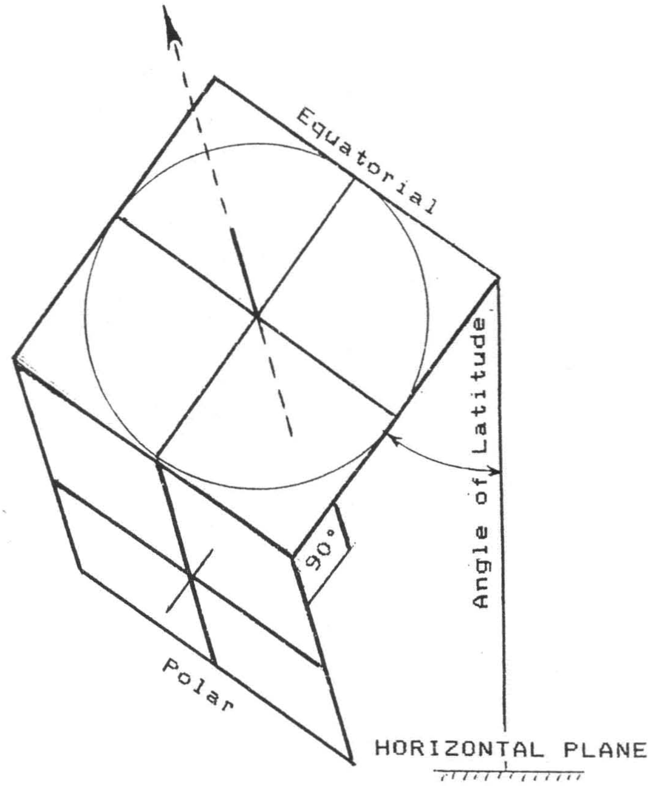
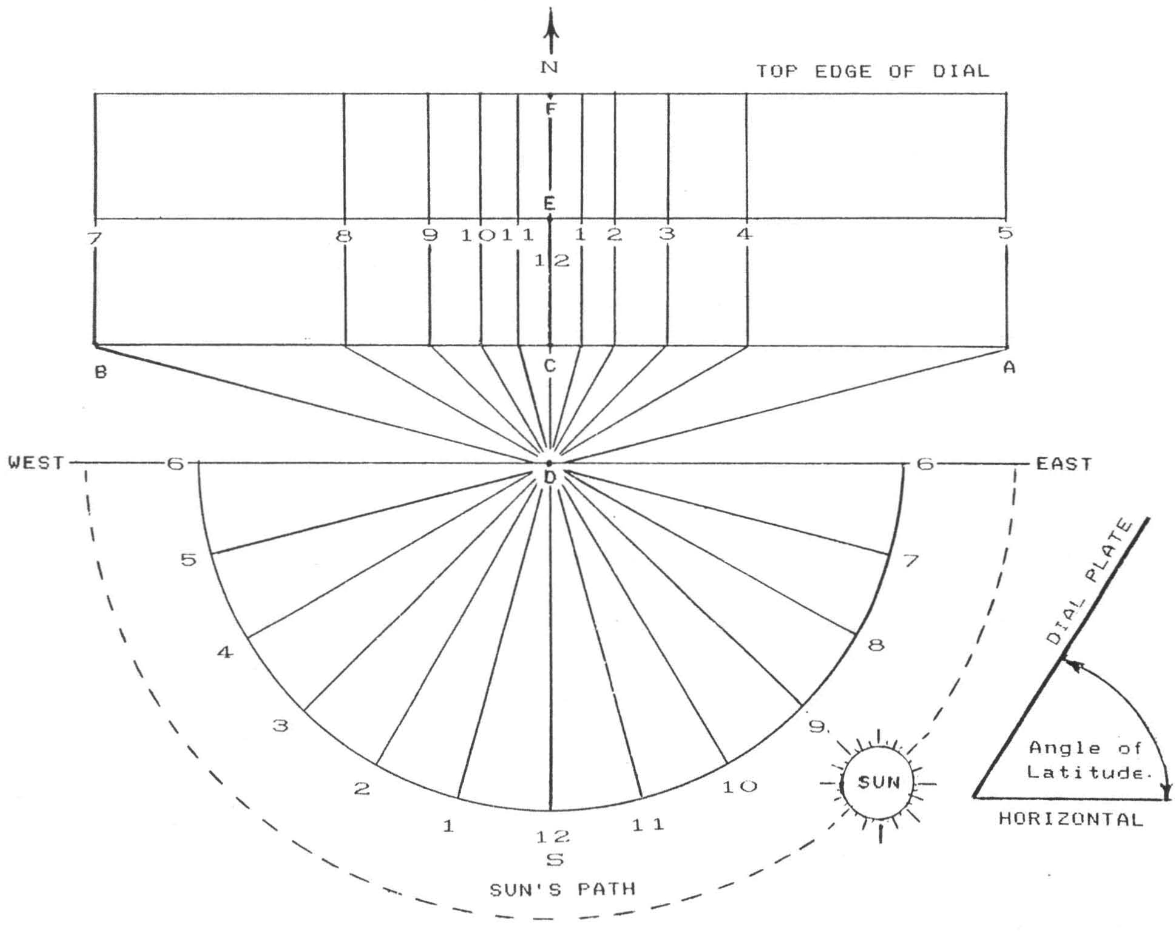



FIG 4: The relation of the Polar and Equatorial Dial

them from 7-12 and 1-5 as shown. Extend each hour line through D on to AB. Through E draw a line parallel to AB and similarly through F. From each point on AB

FIG 5: Delineation of the Polar Dial



where the hour lines contact, drop perpendicular lines to the line running through F and mark the centre line with the hours.

The pin for this dial will be placed at the 12 o'clock mark and must protrude from the base for the same length as CD, and at right angles to the base. If this dial is attached to the dial plate of the equatorial dial with its upper edge at right angles to the North/South line of the equatorial, such that the dial planes are at right angles to each other, it will be placed automatically at the correct angle when the equatorial is inclined at the co-latitude of your local meridian. It is convenient for this purpose to make the equatorial dial on a square plate which will make the attachment of the polar dial much easier. The North/South line of the equatorial dial should touch the 12 o'clock mark of the polar dial.

## TELLING GREENWICH MEAN TIME BY A SUNDIAL

The time zone in Britain is measured from Longitude 0° running through Greenwich, hence G.M.T. [Greenwich Mean Time]. But sundials indicate solar time according to their longitude as illustrated in Fig 7. Dr Robinson is exactly 1° East from Greenwich and when the sun shows 12 noon sun time on his dial, the sun has still to travel 1° or four minutes to be noon sun time at Greenwich, hence his dial is always early with respect to Greenwich by four minutes. Professor Smith lives exactly at 1° West of Greenwich, and when the sun is over the 0° or four minutes before it shows noon on Professor Smith's dial, so his dial will always be 4 minutes late.

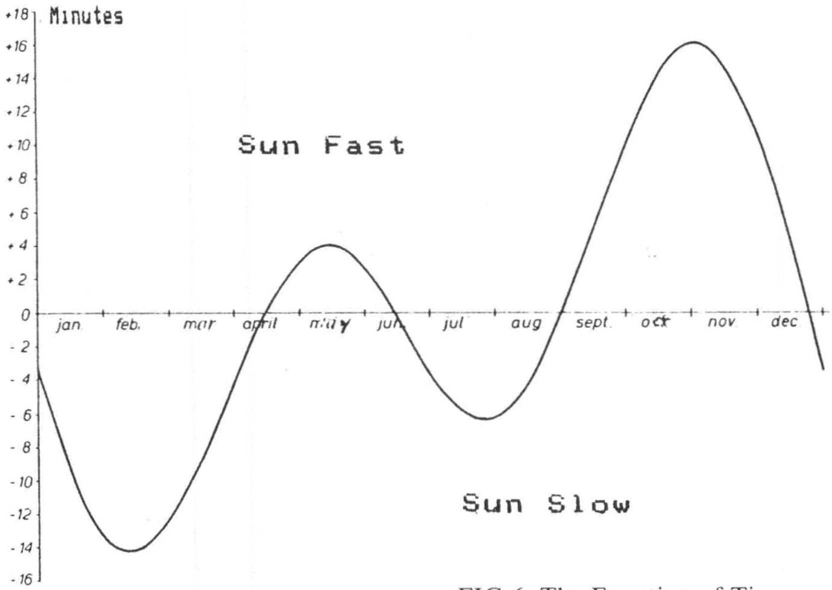



FIG 6: The Equation of Time

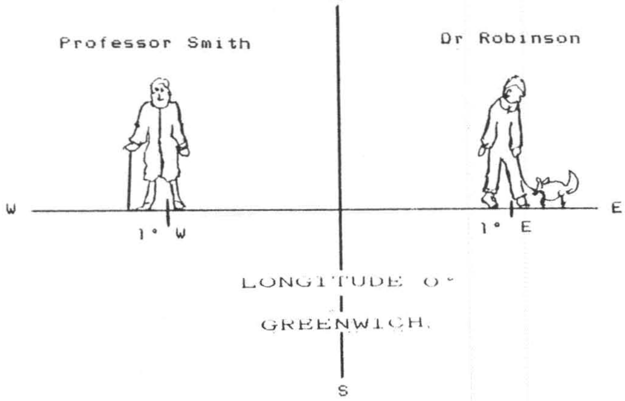



FIG 7: Greenwich Mean Time from a Sundial

## EQUATION OF TIME:

I must now introduce you to the Equation of Time. Do not lose heart when you see this, it is merely to show by how much the sun time is early or late in comparision with an accurate timekeeper showing mean solar time [this gives an equal amount of time to each day of the year]; Fig 6 is thus a graph of the variation of the sun's deviation from "clock time" throughout the year.

Suppose Dr. Robinson looks at his dial on 1st October when the sun indicates midday on his sundial. The sun is 10½ minutes fast on that day so he has to do a little calculation [12.00 - 4 minutes - 10½] and then knows that it is still 14½ minutes before noon at Greenwich, or it is 11.45½ am G.M.T.

Similarly Professor Smith must calculate [12.00 + 4 minutes - 10½ minutes] and when it is noon by the sun on his dial, it is 12.04 - 10½ minutes or 11.53½ am G.M.T.

Note: Summer time merely adds one to the number of each hour and does not alter their distance from Longitude 0°.

*Colin McVean*
*16 November 1990*

# HOROLOGICAL DIALOGUES

In 1675 a book on clocks and watches appeared in London, *Horological Dialogues*, the first of such books in an English text. Its author signed himself J.S. Clockmaker, whom we now know to be John Smith, and although resident in London, is reputed to have served his apprenticeship in Lancashire. He was still only about 27 years of age when he wrote his first book. At the time of its publication, the exact cause of the apparent inequality of the sun's motion was still being debated, a matter of grave concern to clockmakers since the time indicated by mechanical clocks seldom agreed with the true solar time of sundials, nor was the time of the solar day and the sidereal day, as ascertained by observations of the stars, in agreement.

These difficulties are taken up in the third part of *Horological Dialogues* in the form of a dialogue between Art. - the artificer or craftsman clockmaker, and Chi. - this name being of uncertain meaning but which may be an abreviation for chivy, an old form of chevy, which means to harass or nag. Be that as it may, the dialogue is between the searcher and the dispenser of knowledge. The text was transcribed into modern English in 1986 by C. K. Aked and published in 1989 by P.I. Drinkwater as *Horological Dialogues by J.S. Clock-maker.*

## THE THIRD PART

## DIALOGUE I

Of the Inequality of Time in Respect of Artificial Motions: the Nature of it, their Times of Erring with the Quantity of their Error, from whence Several Conclusions are Drawn in Reference to Clocks.

Chi. What is the inequality of time and wherein does it consist?

Art. The inequality of time consists not in the unequal length of days natural but in the unequal length of hours, as given on a sundial which is a thing little sought after, and less understood by those whom it most nearly concerns.

Chi. This is a thing I never before heard of, nor can at present understand, how the hours given can be longer than another, that is how the shadow on a sundial can be longer time in passing from one hour to another at one time of the year, than it is at another, for my part I have never observed it, nor can imagine which way to do it.

Art. There is no way possible to observe it, but by an exact clock, that is regulated by a large pendulum.

Chi. What is the reason for this inequality of time?

Art. In giving the reason or cause there is a great difference, some make the reason of it to be the obliquity of the *Zodiac,* wherein the sun moves; others make the difference between the sun's true longitude, and his right ascension to be the absolute cause; others make the unequal motion of the sun in the *Zodiac* to be the cause (which I incline to) but the cause of this cause, I suppose all are ignorant of, because God in his word never revealed it, and for any other way of knowing it, I suppose, is so far from our attainment that the wisdom of the best astronomer will prove but foolishness, however they may otherwise pretend.

Chi. What reason have you to believe the sun's unequal course to be the cause?

Art. Because the sun in its motion through the *Zodiac* passes equal arcs in unequal times, by reason of its swift and slow motion whereby he fulfils his course from *Libra to Aries* in 178 days (which is the winter half-year) but in passing from *Aries to Libra* he takes up 187 days (which is the summer half-year) being nine days longer in passing through the semi-ecliptic of the summer, than he is through that of the winter, now the sun being thus swift and slow in motion cannot give a true and constant hour by its shadow on a sundial for the motion of the *Primum Mobile* finishes its course in exact times, ie. in twenty-four hours, which well agrees with the sun's mean motion near the equinoctial, but when the sun is in its swift motion, as it happens when inclining to the winter tropic, then there is more time contained in twenty-four hours, as given on a dial, then there was in the equinoctial, and so by consequence every particular hour in the twenty-four must be somewhat longer than those in the Æquator: but when he happeneth to have slow motion as from *Aries to Libras* then there is not so much time contained in twenty-four hours as there is in the Æquator, and so by consequence every hour must also be shorter.

Chi. How this swift and slow motion of the sun should cause this inequality in time I cannot well understand.

Art. Suppose there were on an instrument two circles drawn concentric, and the outmost circle should be graduated into 360 degrees, and every degree into sixty minutes, and suppose that upon this circle thus graduated, there should be some certain figure move, it were naturally from west to east, which in twenty-four hours should move almost fifty-nine minutes of a degree; suppose likewise that in this time of moving fifty-nine minutes, the innermost circle should completely the same way make one revolution, and should continue so to do; that is should always complete its revolution, within itself in twenty-four hours, in which time the other makes fifty-nine minutes of a degree; then suppose this figure on the graduated circle should increase its motion, and should move sixty-one minutes of a degree in the same time as before it moved but fifty-nine; this must needs cause the innermost circle (who before in twenty-four hours finished its course from one conjunction to another, when the figure moved but fifty-nine in twenty-four hours) to be longer time now, because the figure moves faster, and so by consequence, requires more time to be overtaken than it did in its mean motion, the same reason is also for its slow motion; for if the figure move less than fifty-nine (as suppose fifty-eight or fifty-seven minutes) there is less time required for the *primum mobile* like motion of the innermost circle to overtake it, than twenty-four hours.

Chi. What do you infer from hence?

Art. From hence we may infer, that if the hours given by a sundial, increase or decrease in length, according to the slow or swift motion of the sun, that then it is impossible for the most exact clock that was ever made, to keep time with a sundial, but there will be difference, according to the time of the year and course of the sun.

Chi. How is it than possible to adjust a clock, exactly to the hour?

Art. It is possible (when a man rightly understands the course of the sun) to adjust it so, as that if it be set to a sundial at any time it may be right with the same dial that time twelve month, but to adjust it so as to keep touch with a dial the whole year round is impossible.

Chi. At what time will they differ?

Art. If a pendulum truly adjusted (so as to came right that time twelve months without setting) to be set to the hour in *January,* it shall be in *June*, following be too slow by the same dial, if it be set in *June* to the hour, in *January* following, it shall be too fast, but if it be let go the year round, it shall in one half year gain or lose what it lost or got in the other, and so at the year's end come right ot the time it was first set at.

Chi. What may be the quantity of their error?

Art. From *June* to *January* (if it be well adjusted) it will nevertheless gain about forty-four minutes, or almost three-quarters of an hour; from *January* to *June* it will lose near the same time; if set to a dial in *March,* it may lose by *June* something above a quarter of an hour, viz twenty-two minutes; from *June* to *September* it will gain as much and come right again; from *September* to *December* it will gain about twenty-two minutes, but from *December* to *March* it will lose it and come right again. Whence observe that clocks set to the hour, when the sun is in either of the tropics, continues gaining and losing the whole year round, and never agree with the same dial, till that time twelve month; but if they are set when the sun is in either of the equinoctial points, then they may agree with the same dial twice in the same time of year, and their gaining and losing will never be so extreme, as when set in the tropics, for if it be set in *March* (or the equinoctial of *Aries*) it shall have lost in *June* but twenty-one or twenty-two minutes, and in *September* following it will agree with the same dial again, from thence to *December* it will gain as much, and from thence to *March* it will lose it and come right again; so that form hence we may conclude that those clocks, which go to a quarter of an hour or something more in three months are the nearest that can be brought to keep true time with the sun, let them be of what form, kind, or price whatsoever.

Chi. What is the most true and exact way of adjusting clocks by the sun?

Art. If you would adjust a clock exactly to the sun, so that twelve months after it may agree with the same dial (if set when the sun is in the tropics, or agree with the same dial twice in the year, when set in the equinoctials) do thus, in the equinox of *March* let it be set to a true dial that sheweth minutes, and when the sun is in the meridian; then in *June* following observe the difference between clock and the dial, which if it be about twenty-two minutes too slow then conclude it goeth well, but if it be more than twenty-two minutes or less, then you must rectify it, accordingly, as hath been formerly taught and thus you may rectify it, to any other time, if you consider the difference that happeneth after so many months going, from any time of setting.

**NOTES:** John Smith was, in 1675, still treating the motion of the sun from a Ptolemaic point of view although Copernicus had published his book *Concerning the Motions of the Heavenly Bodies* in 1543, where he stated that the Sun was at the centre of the Solar system, and not the Earth. Copernicus's treatise was banned by the Roman Catholic Church until 1758. Thus John Smith speaks of a 'natural day' of twenty-four hours which we now call a sidereal day, measured by two consecutive passages of a chosen star across the meridian; ie. treating the matter from a point of view of the heavenly sphere turning uniformly around the earth. It is not clear how John Smith reconciled this with the 365¼ days of the year, since his 'natural' day is our sidereal day of approximately 23 hours 56 minutes 4,0956 seconds, of which there are 366¼ days in the year because of the extra rotation of the earth in travelling around the sun. His explanations therefore only take account of the varying velocity of the earth in its elliptical orbit around the sun (which he describes as the sun's varying motion). The first Equation of Time Table was published in Nicholas Stephenson's *Royal Almanack,* published in London, 1676; the values being supplied by John Flamsteed, the Astronomer Royal. John Smith published his own figures in a pamphlet *The Equation of Time Demonstrated,* 1678, a copy of which is in the Bodleian Library, Oxford. John Smith published a second pamphlet in 1679, *The Equation of Time, with a Table of Equations for the adjusting or managing of Pendulum Clocks,* and included these explanations in his later books.

The interest in this subject is indicated by the letter sent by the clockmaker Peter Nelson of Durham to Robert Hooke, begging him for an explanation of why the sun's apparent motion was unequal. He had been laughed at because he maintained his clocks were accurate and it was the sun which was incorrect, ie. the time given by sundials. The problem was only later resolved by adopting the mean solar day of exactly twenty-four hours for each day of the year, and putting up with the minor inconvenience of mean and true solar time not agreeing except on four occasions in the year. Until the application of long heavy pendulums to clocks, the problem was academic since the diurnal error of any mechanical clock was far greater than the largest difference in the duration of any two consecutive days. Until the reasons for the variations became known, clocks were set at noon as the sun crossed the meridian, the most convenient and accurate part of the day, so for a long time clocks were really measuring changing hours indirectly by constant adjustment to run 24 hours from noon to noon. When the long heavy pendulum clock with its increased accuracy of rate was introduced, the cumulative error of the daily changes was soon made clear, and it only became possible to set these clocks daily and accurately to time with a sundial in conjuction with the use of an Equation of Time Table giving the difference between true solar time as indicated by the sundial, and the mean time indicated by the clock.

This was to become the greatest service rendered by sundials until the transmission of accurate time signals from astronomical observatories by electrical methods, and a reason for so many sundials on churches with tower clocks since this was the only time standard conveniently available to the clock keeper.

# DIALOGUE II

**OF REFRACTIONS WHAT IT IS, AND WHEN IT HAPPENETH, WITH SEVERAL CONCLUSIONS DRAWN FROM IT, IN REFERENCE TO CLOCKS**

Chi. What is the refraction of the sun's beams, and how is it caused?

Art. Refraction of the sun is when the sun appeareth higher in altitude than indeed he is, and is caused by the moist and humid vapours which continually arise from off the earth, which naturally represents all things, that are seen through them, to be larger in bulk and higher in altitude than indeed they really are, this makes the sun, moon and stars, when they first arise, to appear so large in magnitude, which continually diminishes according as they ascend above the horizon, until being elevated above all vapours they are again reduced in appearance to their natural magnitude, and as those vapours would make them appear to us of greater bulk and magnitude than otherwise they would, so they cause them to appear higher in altitude so that we see the sun visibly risen before he is naturally above the horizon.

Chi. How is this proved?

Art. It may be proved thus: take an horizontal dial, that is large and truly drawn, place it exactly in its true position, which having done, left a pendulum clock, that keepeth true time, be (about twelve of the clock) set exactly to it; the next morning, if the sun shine observe how they agree and you shall find that at the first rising of the sun there will be such difference, which will by little and little diminish, according as the sun gets above the strength of those vapours, until at last they come exactly together, which could not be, if her altitude were not by these refractions, made apparently higher than her true place.

Chi. What conclusions may be drawn from hence?

Art. Since it is so that those vapours make the sun at his rising or setting to appear higher to us than naturally he is, this must by consequence give a false shadow on all sundials, both at its rising and setting, because the hour lines drawn on sundials, are designed to receive the shadow of the sun from its true place, and not from his apparent position; and so by consequence all dials whatsoever cannot at those times given the true hour, because they receive not their shadow from the sun's true place, but from his apparent; therefore if your watches and clocks agree not with your dial, you are not to conclude the fault to be in their motion (if they have gone well before) but in the refracted shining of the sun.

Chi. What altitude may the sun attain before we may put confidence in a sundial?

Art. For this I shall give you a Table made by observation as near as possible to the truth.

**A TABLE OF THE SUN'S REFRACTION IN TIME ACCORDING TO THE DEGREES OF ALTITUDE:**

| Ø Altitude | Difference | Ø Altitude | Difference |
|---|---|---|---|
| 0 | 18.00 | 12 | 04.30 |
| 1 | 14.00 | 13 | 04.15 |
| 2 | 11.00 | 14 | 04.00 |
| 3 | 09.00 | 15 | 03.40 |
| 4 | 08.00 | 16 | 03.20 |
| 5 | 07.30 | 17 | 03.00 |
| 6 | 07.00 | 18 | 02.35 |
| 7 | 06.30 | 19 | 02.00 |
| 8 | 06.00 | 20 | 01.20 |
| 9 | 05.30 | 21 | 01.00 |
| 10 | 05.00 | 22 | 00.30 |
| 11 | 04.45 | 23 | 00.00 |

**A TABLE OF THE SUN'S REFRACTION IN TIME ACCORDING TO THE DEGREES OF ALTITUDE:**

The use of this Table is thus, first find the sun's altitude in the left-hand column, entitled Ø *Altitude*, and right against it you have the minutes and seconds, which those dials vary when the sun has such degrees of altitude; as for example, when the sun first appears, a dial will differ from the true time by 18 minutes; when he has three degrees of altitude, the difference is 9 minutes, when he has 9 degrees of altitude the difference is 6 minutes 30 seconds, &c, so that it will not be safe setting either a watch or clock to the hour given on a sundial, until the sun has attained 20 degrees of altitude above the horizon, until which time the refraction is something sensible.

Chi. Tell me precisely what hours are fittest for that purpose?

Art. The best times for setting a clock or watch to the time, on a dial is May, June and July, between the hours of 7 in the morning and 5 in the afternoon, in April and August between the hours of 8 in the morning, and 4 in the afternoon; in February and September, between the hours of 10 and 2, the other months it will not be safe setting them until near noon.

Chi. Suppose a watch should be set to a sundial betimes in the morning, what then?

Art. Then it will go right with the same dial all the prime part of the day after, but will differ as much as the refraction was when it was set to the same dial.

Chi. Are not these refractions always equal throughout the year?

Art. No, they are greater in winter than in the summer, greater in moist weather than in dry, greater near seas or large rivers than on the remoter parts of dry land, and greater in the morning than they are in the evening, all which being duly considered, may prove of good use for the business for which this discourse has designed it, viz. The true keeping, and right managing of clocks and watches whatsoever; so that whensoever you shall find your watches or clocks differ in the same day from your dial, you may by knowing the reason of it prevent those mistakes which otherwise might arise.

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The foregoing explanations were made when the understanding of optical science was in its infancy. The true cause of the refractional error is the varying density of the air from almost zero at the limits of the earth's atmosphere to the full amount at sea level. Light rays from a source are bent towards the normal when passing from a rare to a denser medium and the sun's rays pass through over one thousand miles of the atmosphere at apparent dawn, when the earth has to rotate another 4.5 degrees before the true dawn begins. The effect of this long passage through air is to remove the shortest wavelengths of light and the light transmitted is mainly red as can be seen in a lunar eclipse when the dark parts of the noon become ruddy by the sun's light passing through the atmosphere and refracted towards the moon. The addition of moisture to the atmosphere increases its optical density, hence the refractive effects increase as stated by John Smith. However the apparent increase of size of the sun and moon when on the horizon is partly an optical illusion since the diametrical size measured by an instrument differs little whether on the horizon or at the zenith. The refractive errors are normally ignored or unknown by the observer and are never allowed for in the ordinary form of sundial construction. For true solar time the refractive effects and the Equation of Time differences must be taken into account in the early and late parts of the daylight, and the Equation of Time correction only in the middle part of the daylight hours.

Thus the computation of the true solar time at extremes of the daylight hours is not an easy matter because the values given in John Smith's tables are average values which are modified slightly according to the state of the atmosphere. Nevertheless, once the sun has achieved a reasonable height in the heavens, the error is within the limits of indication by most sundials and can therefore be ignored. There are few sundial sites where the sun can be seen rising above the true horizon, because of buildings, trees, locally elevated ground, and so on. The best time for a sundial indication is at noon when the Equation of Time values can be employed directly to obtain mean time within a minute or so.

*Charles K. Aked*
*29th November 1990*

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**B.S.S. CAMBRIDGE MEETING**

A meeting of the British Sundial Society will be held in Cambridge on 20, 21 and 22 September 1991. It will include a tour of the Cambridge sundials, of which there are unique examples, plus a lecture programme. Members wishing to partake in this weekend meeting may make a provisional booking with the Programme Secretary, Mr. Mike Cowham. His address may be found on the inside back cover of this issue. Full details of the meeting will be published later. The number of places is limited and an early application, together with a cheque for £20, is advisable to avoid possible disappointment. The full cost of the meeting will be given when the application forms are sent out, but will be similar to that of previous meetings. Members who wish to lecture at this meeting are invited to submit a brief summary of the aspect of dialling on which they wish to speak, again to Mr. Cowham.

# A LATITUDE INDEPENDENT SUNDIAL

**EDITOR'S NOTE:**

Because of the complexity of the mathematical terms causing difficulties in setting, it has been necessary to produce this article in facsimile. It is hoped that this does not inconvenience readers greatly as this process is considerably simpler and less expensive than re-setting.

# A LATITUDE-INDEPENDENT SUNDIAL

**BY J.G. FREEMAN**

**University of Bradford**

**ABSTRACT**

Existing types of sundial require the latitude at which they are to be used to be known, either in their construction or in their adjustment for use.

Consideration of the formulae relating to a spherical triangle on the celestial sphere, however, shows that the sun's hour angle can be determined from the values of the sun's declination, altitude and azimuth, without reference to the value of the observer's latitude.

This suggests that it might be possible to devise a sundial which would do this, and such a dial is here described. Its gnomon is a thin flat plate one edge of which has the shape of part of the curve

$$x^{2/3} + y^{2/3} = h^{2/3}.$$

1. *Introduction.* Consider the spherical triangle formed by the sun, zenith and north pole on the celestial sphere, with these three points denoted by **X**, **Z** and **P** respectively. Let the sun's altitude, declination, azimuth (west from north) and hour angle be denoted by $a$, $\delta$, $A$ and $H$ respectively; let the observer's latitude be Ø (positive if north of the equator, negative if south).

The angles at **Z** and **P** of the spherical triangle **XZP** are $A$ and $H$ respectively, and the sides **ZP**, **PX** and **XZ** subtend angles $90° - \phi$, $90° - \delta$ and $90° - a$ respectively at the centre of the celestial sphere. Consideration of the formulae relating to a spherical triangle shows that $H$ (= $15n°$ where $n$ is the local apparent time — 12 hours) can be determined from the values of any three of the four variables $\delta$, $a$, $A$ and $\phi$, ie. independently of one of them. Thus one might classify sundials according to which one of the four variables $\delta$, $a$, $A$ and $\phi$ is not involved in the determination of the time, as follows:

*Declination-Independent Dials*

Common horizontal, vertical and equatorial.

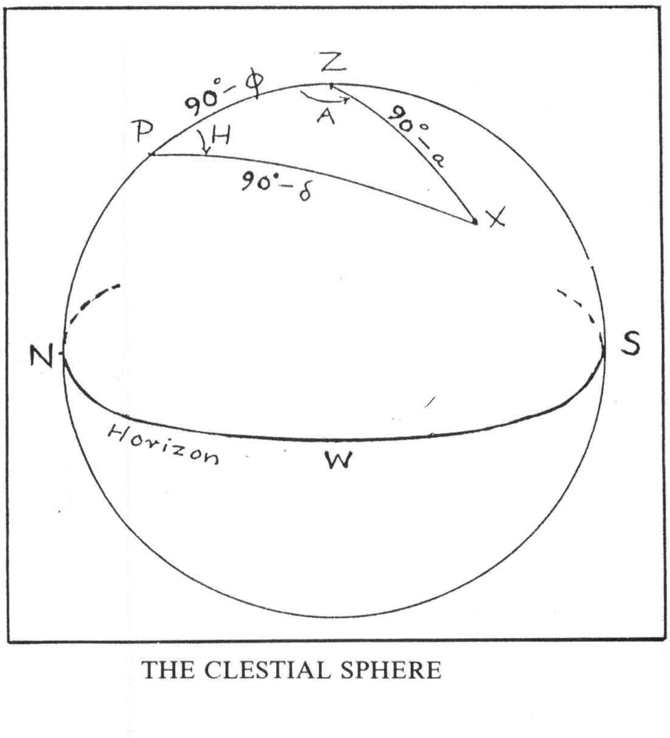
*Altitude-Independent Dial*

*Horizontal elliptical (which has a vertical rod for gnomon).*

*Azimuth-Independent Dials*

Ring, analemmatic (ie. a common horizontal combined with an elliptic horizontal), pillar, disk, Capuchine and Regiomantanus (none of which requires the north to be known).

All the dials listed above require the latitude to be known, either in their construction (as with the common horizontal) or in adjusting them for use (as with the ring). There is no existing dial belonging to the fourth class, *Latitude-Independent,* and the dial to be described below is the outcome of the author's attempt to fill this gap. It may be used at any latitude (except at




THE CLESTIAL SPHERE

the poles); but it is, perhaps, more a scientific curiosity than an instrument of practical use.

2. *The Components of the Dial and Method of Use.* Rather than first presenting the theory of the latitude-independent sundial, a model of the dial will be described. The principle upon which the dial is based will be apparent from the details of the construction of the model. A photograph of the model is given in figure 1, and a key to this photograph is presented in figure 2.

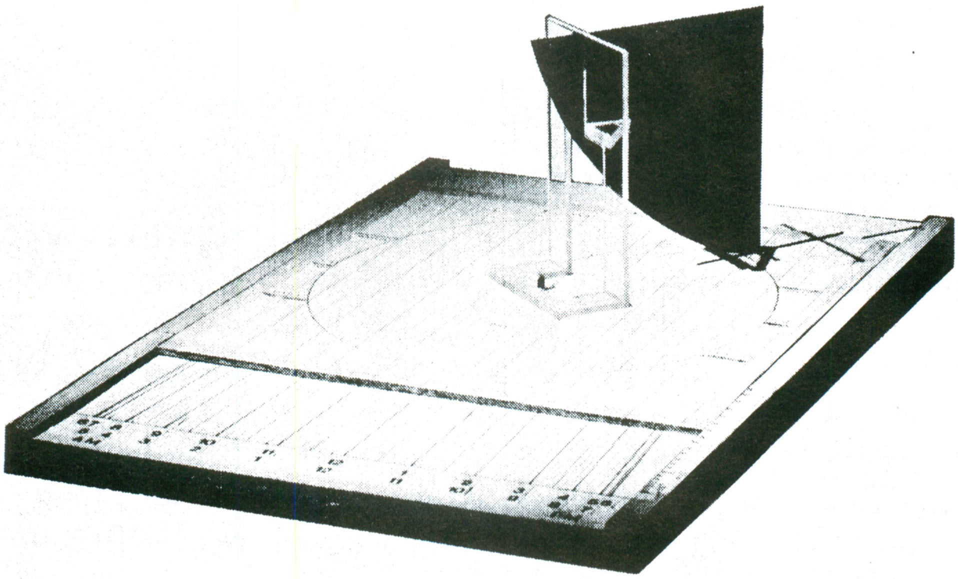


FIG. 1—Photograph of a model of the latitude-independent sundial. See figure 2 for a schematic illustrating the use of the dial.

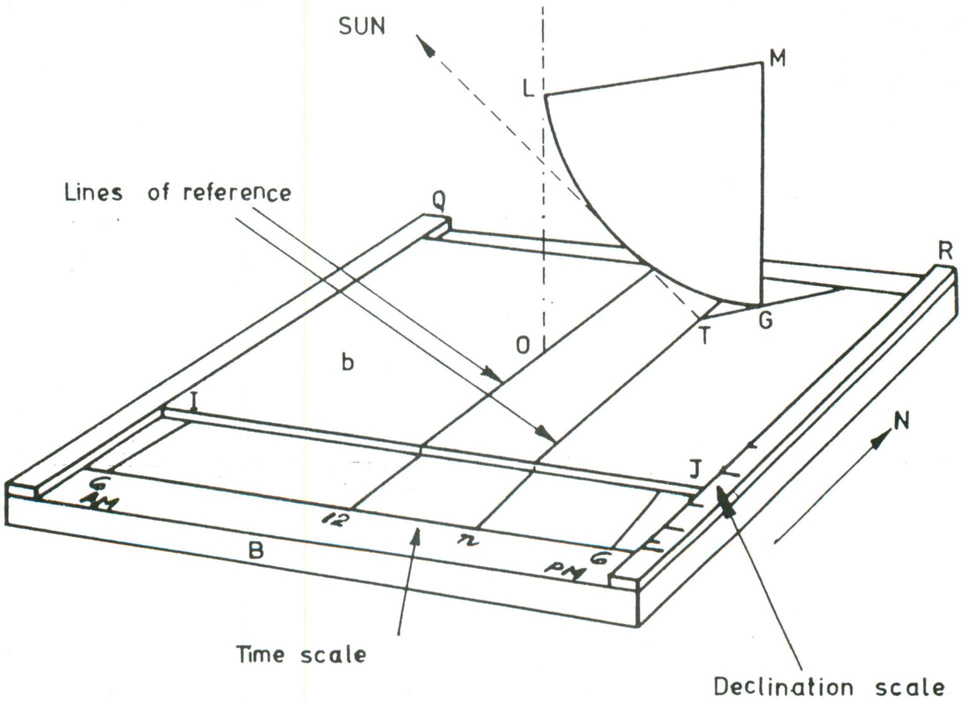



FIG. 2—A schematic illustrating the sundial in use. The shadow **TG** of the gnomon indicates a local apparent time of *n* hours p.m.

The gnomon **LMG** is a thin flat vertical plate with a curved edge **GL**, the shape of the curve being as specified in Section 5. This is supported by a frame (omitted from figure 2 for the sake of clarity) which turns on a pivot at the centre **O** of a square horizontal thin board **b**, so that the gnomon may be rotated about a vertical axis **OL** with **GM** remaining vertical and **G** sliding on the board **b**.

The board **b** rests on a horizontal base-board **B**, sliding between two runners **Q** and **R**. On **b**, lines of reference are drawn, parallel to the runners and uniformly spaced, every fifth line being emphasized to assist the eye (only two of these lines are shown in figure 2); in the model, graph paper with lines spaced at 0.1 inch was mounted on **b** to provide these lines. One runner **R** carries a scale with divisions corresponding to values of the sun's declination as described in Section 4.

On the base-board **B** is drawn a time scale consisting of lines labelled with hours, and intermediate lines for smaller intervals, as described in Section 3.

In use, the dial is orientated so that the lines of reference on **b** run from south to north, and the sliding board **b** is positioned between the runners so that the edge **IJ** of **b** is opposite the division on the declination scale corresponding to the current value of the sun's declination. The gnomon is rotated until its plane passes through the sun, as evidenced by its shadow becoming a line of the same thickness as the gnomon itself; the local apparent time is then indicated on the time scale at the edge **IJ** of the board **b** by the line of reference on which lies the terminator **T** of the shadow **TG** of the curved edge of the gnomon.

Each hour line of the time scale (except those for 6 a.m. and 6 p.m.) is labelled with two different times; which reading is the correct one in any particular instance may be determined in most cases by observing the position of **T** with respect to a diagram on the board **b**, as described in Section 6 (omitted from figure 2 for the sake of clarity).

3. *Construction of the Time Scale.* In the spherical triangle **XZP**

$$\sin H/\sin(90° - a) = \sin A/\sin(90° - \delta)$$

or

$$\cos\delta \sin H = \cos a \sin A\,. \tag{1}$$

This is the formula from which $H$ may be determined independently of the latitude $\phi$.

In the following, the sun's azimuth will be supposed to be west, but similar considerations will apply when the azimuth is east.

In figure 3, **S** and **N** denote the points in which the line of reference

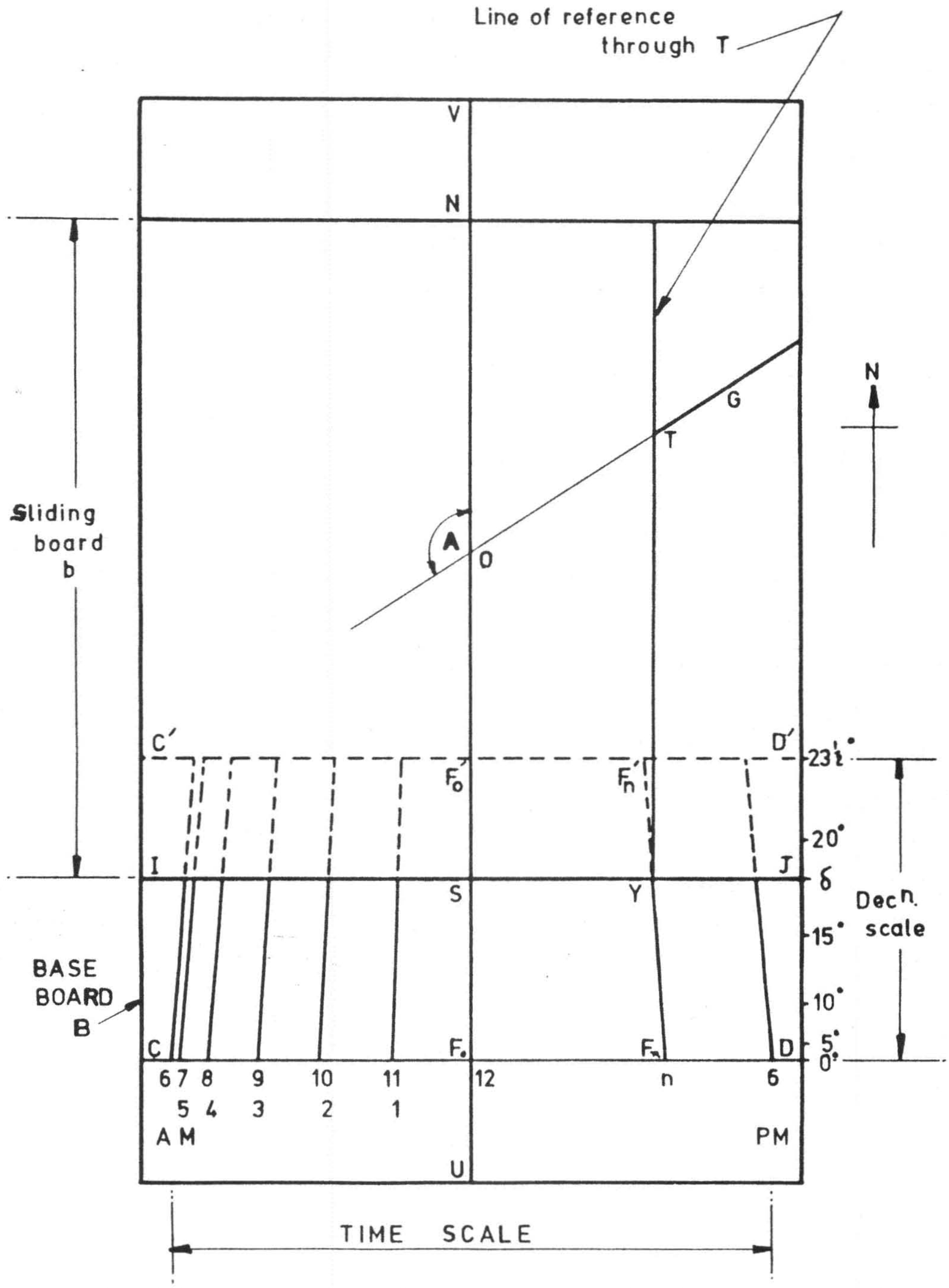



FIG. 3—Details of the construction of the time and declination scales. See the text for an explanation of the symbols.

through **O** meets the edges of the sliding board **b**, **N** being the north end of this line. **U** and **V** denote the points in which the line on the base-board **B** vertically below **SN** meets the edges of **B**.

The point at which the line of reference through **T**, the terminator of the shadow of the curved edge of the gnomon, meets the edge **IJ** of the sliding board **b** is denoted by **Y**; then $SY$ (the length of the line **SY**) equals the perpendicular distance of **T** from **SN**, i.e.

$$SY = OT \sin A. \qquad (2)$$

If the shape of the curved edge of the gnomon can be chosen such that

$$OT = h \cos a \tag{3}$$

where $h$ is any constant, then from equations (2) and (3)

$$SY = h \cos a \sin A; \tag{4}$$

*this is independent of the latitude.* From (1) and (4)

$$SY = h \cos \delta \sin H. \tag{5}$$

Hence

$$SY = h \cos \delta \sin 15n° \tag{6}$$

if the local apparent time is $n$ hours p.m.

Thus the time scale and the declination scale have to be so constructed that the hour line indicating $n$ hours p.m. intersects **IJ** at a point distant $h \cos \delta \sin 15n°$ from **S**, if the sun's declination is $\delta$.

Taking any two points **D** and **D′** on the inner edge of the runner **R** for the 0° and 23½° divisions of the declination scale, the positions of the edge **IJ** on the base-board **B** when the declination is 0° and 23½° are denoted by **CD** and **C′D′** respectively. Lines on **B** which are underneath the sliding board **b** are shown as broken lines in figure 3.

If the hour line indicating $n$ hours p.m. meets **CD** and **C′D′** at $\mathbf{F_n}$ and $\mathbf{F_n}'$, and if **UV** meets **CD** and **C′D′** at $\mathbf{F_0}$ and $\mathbf{F_0}'$, then:

when $\delta = 0°$, $SY = F_oF_n$ and, from (6),

$$F_oF_n = h \sin 15n°; \tag{7}$$

when $\delta = 23\tfrac{1}{2}°$, $SY = F_o'F_n'$ and, from (6),

$$F_o'F_n' = h \cos 23\tfrac{1}{2}° \sin 15n°. \tag{8}$$

Thus, to construct the time scale, points $\mathbf{F_n}$ and $\mathbf{F_n}'$ are marked on **CD** and **C′D′** in accordance with equations (7) and (8) for $n = 0, 1, 2, 3.....12$, $\mathbf{F_n}$ is joined to $\mathbf{F_n}'$ for each value of $n$, and the line $\mathbf{F_nF_n}'$ is labelled with the time $n$ hours p.m. Since

$$\sin 15(12 - n)° = \sin(180 - 15n)° = \sin 15n°,$$

the hour line for $12 - n$ hours p.m. will be the same as that for $n$ hours p.m., and each hour line (except that for 6 p.m.) will be labelled with two different hours. Hour lines for a.m. are similarly constructed.

Intermediate lines for intervals of ten minutes between noon and 4 p.m. are inserted by assigning intermediate values to $n$. As $n$ approaches 6, however, the space between consecutive hour lines becomes smaller, and therefore intermediate lines are inserted only for 20-minute intervals between 4 and 5 p.m., and for 5:30 between 5 and 6 p.m.

The a.m. hour lines are shown in figure 3, and the complete scale in figure 4.

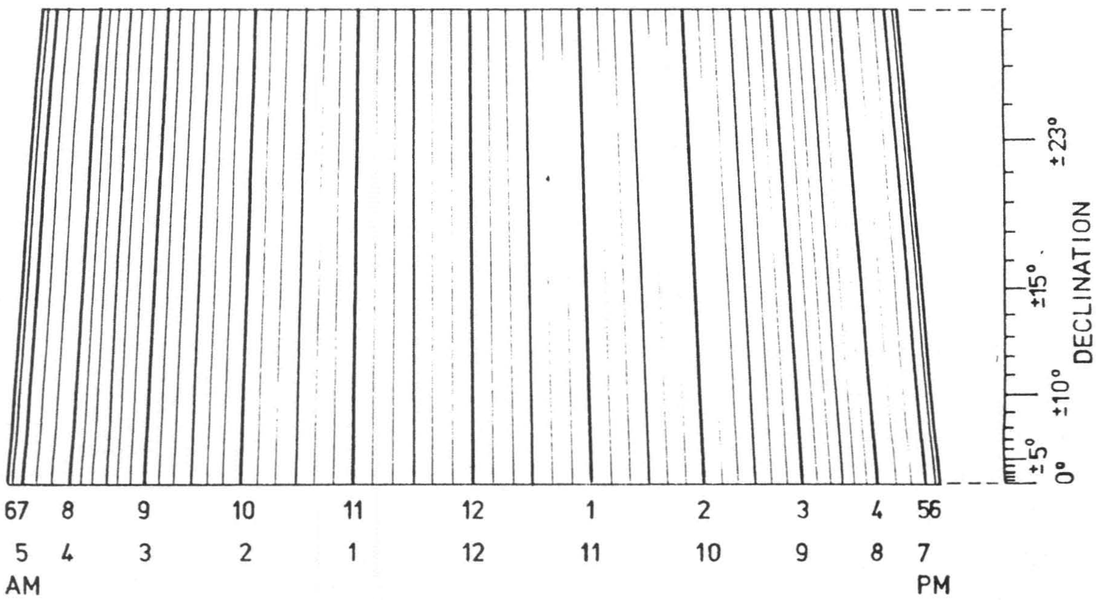



FIG. 4—The completed time and declination scales.

4. *Construction of the Declination Scale.* In figure 3,

$$F_oS/(F_oF_n - SY) = F_oF_o'/(F_oF_n - F_o'F_n')$$

since each is the cotangent of the angle between $\mathbf{F_oF_o'}$ and $\mathbf{F_nF_n'}$. Hence, using equations (6), (7) and (8)

$$F_oS/(h \sin 15n° - h \cos \delta \sin 15n°)$$
$$= F_oF_o'/(h \sin 15n° - h \cos 23^1/_2° \sin 15n°).$$

Thus

$$F_oS = F_oF_o'(1 - \cos \delta)/(1 - \cos 23^1/_2°). \quad (9)$$

This is the distance between the divisions corresponding to declinations 0° and δ on the declination scale, and divisions at intervals of 1° from 0° to 23° may now be inserted on this scale using equation (9). Since this equation involves only the cosine of δ, the same scale serves for both positive and negative declinations.

Divisions of the declination scale at intervals of 5° are shown in figure 3, and the complete scale in figure 4.

5. *The Gnomon.* The construction of the time scale described in Section 3 is based on the assumption that the shape of the curved edge of the gnomon is such that $OT = h \cos a$.

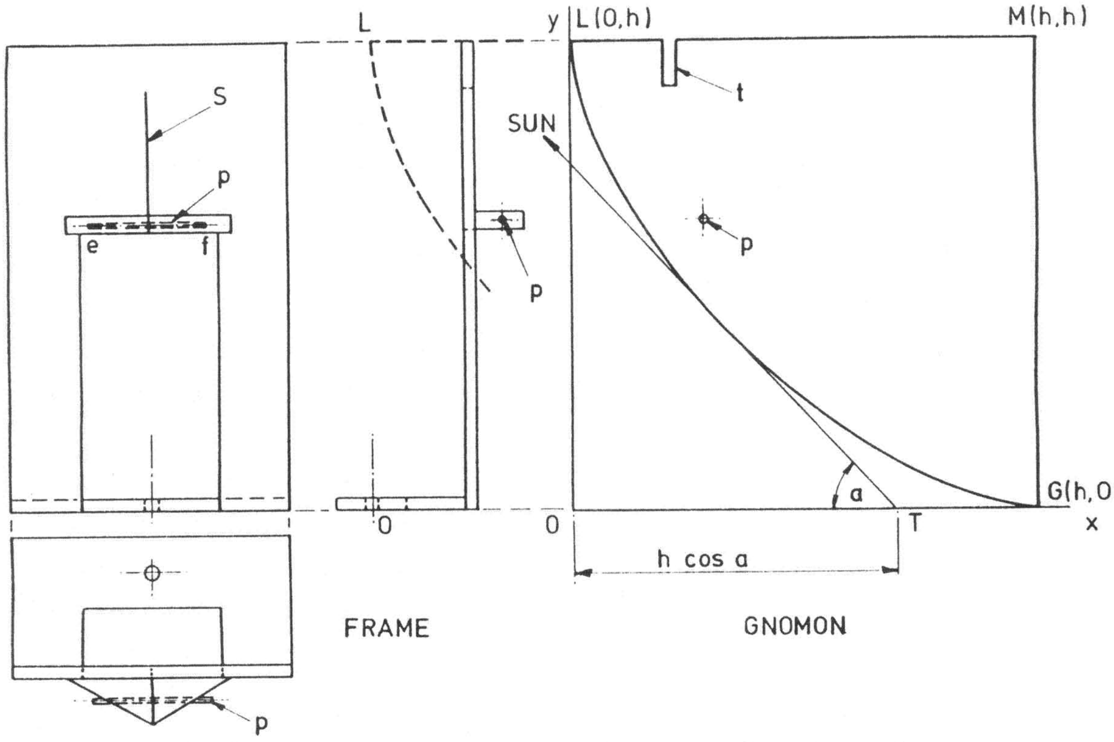



FIG. 5—Details of the gnomon and its supporting frame. The shape of the gnomon, made from sheet metal, is shown at right, while the frame, made from Perspex, is illustrated at left.

Taking **OG** and **OL** as $x$ and $y$ axes as shown in figure 5, the equation of the curve possessing the required property is obtained as follows. Since the tangent through **T** to the curved edge of the gnomon passes through the sun, it makes an angle $a$ with **OG** and therefore has an intercept of $h \sin a$ on **OL**; hence the equation of this tangent is

$$x \sec a + y \operatorname{cosec} a = h. \qquad (10)$$

To determine the envelope of these tangents, differentiate equation (10) with respect to $a$:–

$$x \sec a \tan a - y \operatorname{cosec} a \cot a = 0. \qquad (11)$$

From (10) and (11),

$$x = h \cos^3 a \quad \text{and} \quad y = h \sin^3 a,$$

and elimination of $a$ from these two relations gives for the equation of the envelope

$$x^{2/3} + y^{2/3} = h^{2/3}. \qquad (12)$$

To construct a template for the gnomon, the curve defined by (12) is plotted for positive values of $x$ and $y$ between 0 and $h$, where $h$ is the length chosen for the straight edges of the gnomon, and the point **M**($h$,$h$) is joined to **G**($h$,0) and **L**(0,$h$).

For the present model, the gnomon was made of 0.02-inch sheet steel with $h = 5$ inches, and the frame was made of Perspex, the parts being cemented together. In figure 5, **t** and **s** denote slots in the gnomon and frame; these were slotted together and the gnomon secured with a pin **p**. The dimensions of the frame were not important, except that it was essential to ensure that they were such that the upper edge **ef** of the opening met the gnomon above the curved edge in order that the frame should not interfere with the formation of the shadow **TG**.

6. *Discrimination Between Day and Night Readings*. Each hour line of the time scale (except those for 6 a.m. and 6 p.m.) is labelled with two different times. There is no difficulty in deciding which of the two indicated times is the correct one in northern latitudes when $\delta < 0$, and in southern latitudes when $\delta > 0$, for the sun then rises after 6 a.m. and sets before 6 p.m.

In northern latitudes when $\delta > 0$, and in southern latitudes when $\delta < 0$, it is possible (with certain exceptions) to discriminate between the two indicated times by observing in which region of a diagram on the board **b** the point **T** lies. This diagram is shown in figure 6. When **T** lies in a region

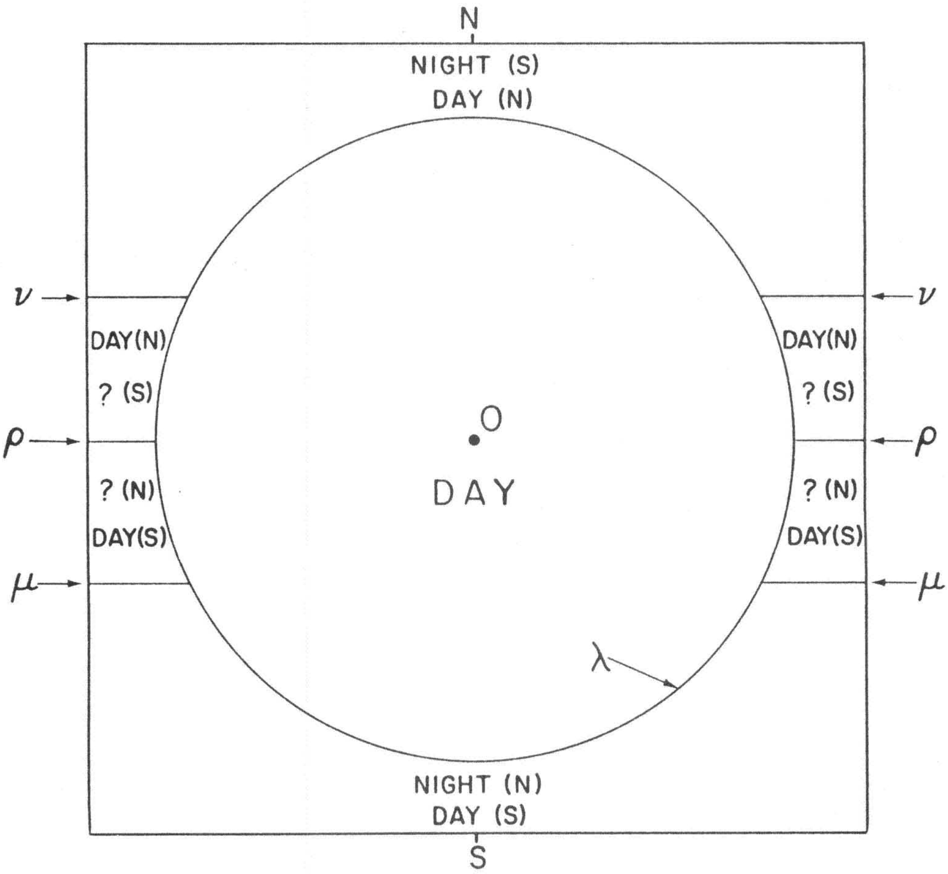



FIG. 6—The discriminating diagram used to distinguish, for a given position of the shadow, which of the two time values on the time scale is appropriate: DAY (<6 hours from noon) or NIGHT (>6 hours from noon). This will depend, in some cases, upon whether the observer is in the northern hemisphere (N) or southern hemisphere (S). Further explanation is given in the text.

labelled DAY the time is after 6 a.m. and before 6 p.m., and when **T** lies in a region labelled NIGHT the time is before 6 a.m. or after 6 p.m.

The diagram consists of a circle $\lambda$ with centre **O** and radius $h \cos 23\frac{1}{2}°$, and the segments outside $\lambda$ of three lines $\mu$, $\rho$ and $\nu$ perpendicular to **SN**. The lines $\mu$ and $\nu$ are at distance $h \sin 23\frac{1}{2}°$ from **O**, $\mu$ to the south and $\nu$ to the north of **O**, and the line $\rho$ passes through **O**.

To determine whether a region of the discriminating diagram corresponds to a DAY or NIGHT reading, the sign of $\cos H$ for **T** lying within that region will be obtained from equations (13) or (15) below. (The sun's azimuth will be taken as west, but similar considerations apply if the azimuth is east.) Thus,

$$\text{when } \cos H > 0,\ 0° \leqslant H < 90°,\ 0 \leqslant n < 6, \text{ hence DAY;}$$

$$\text{when } \cos H < 0,\ 90° < H \leqslant 180°,\ 6 < n \leqslant 12, \text{ hence NIGHT.}$$

From the spherical triangle **XZP**

$$\sin a = \sin \phi \sin \delta + \cos \phi \cos \delta \cos H, \qquad (13)$$
$$\sin \delta = \sin \phi \sin a + \cos \phi \cos a \cos A. \qquad (14)$$

Substitution for $\sin a$ from (13) in (14) gives

$$\sin \delta \cos \phi = \sin \phi \cos \delta \cos H + \cos a \cos A. \qquad (15)$$

*A. Terminator Inside Circle.* If **T** lies inside the circle $\lambda$, $OT < h \cos 23\frac{1}{2}°$; i.e. $\cos a < \cos 23\frac{1}{2}°$ and $a > 23\frac{1}{2}°$. From (13),

$$\begin{aligned}\cos \phi \cos \delta \cos H &= \sin a - \sin \phi \sin \delta > \sin 23\tfrac{1}{2}° - \sin \phi \sin \delta \\ &\geqslant \sin \delta (1 - \sin \phi) > 0 \text{ if } \delta > 0, \text{ and} \\ &\geqslant \sin(-\delta)(1 + \sin \phi) > 0 \text{ if } \delta < 0.\end{aligned}$$

Hence $\cos H > 0$, therefore *if* **T** *lies within* $\lambda$ *the reading is DAY for all latitudes.*

*B. Terminator Outside Circle.* Next suppose **T** lies outside $\lambda$ and south of **O**. Then $A$ is acute, $\cos A > 0$, and from (15)

$$\sin \delta \cos \phi - \sin \phi \cos \delta \cos H = \cos a \cos A > 0,$$

or

$$\sin \phi \cos \delta \cos H < \sin \delta \cos \phi.$$

As noted above, we need only consider the situation where $\phi$ and $\delta$ are of the same sign.

(i) If both $\phi, \delta < 0$,

$$\cos H > \tan \delta \cot \phi > 0, \text{ i.e. } \cos H > 0 \text{ (DAY).}$$

(ii) If both $\phi, \delta > 0$,

$$\cos H < \tan \delta \cot \phi > 0$$

from which the sign of $\cos H$ cannot be determined. If, however, **T** lies south of $\mu$ also, $OT \cos A > h \sin 23\frac{1}{2}°$, $\cos a \cos A > \sin 23\frac{1}{2}°$, and from (15)

$$\sin\delta\cos\phi - \sin\phi\cos\delta\cos H > \sin 23^1/_2{}^\circ,$$

or

$$\sin\phi\cos\delta\cos H < \sin\delta\cos\phi - \sin 23^1/_2{}^\circ$$
$$\leqslant \sin 23^1/_2{}^\circ(\cos\phi - 1) < 0, \text{ i.e. } \cos H < 0 \text{ (NIGHT)}.$$

In the remaining region between $\mu$ and $\rho$ the sign of cos $H$ has not been determined, and it can be shown that there exist positions of **T** in this region for which cos $H$ may be positive or negative depending on the latitude north.

Corresponding results apply for **T** lying outside $\lambda$ and north of **O**. Hence *if* **T** *lies outside circle* $\lambda$ *and south of line* $\mu$, *the reading is NIGHT or DAY according as latitude is N or S; if* **T** *lies outside circle* $\lambda$ *and north of line* $\nu$, *the reading is NIGHT or DAY according as latitude is S or N.*

Hence also, *if* **T** *lies outside* $\lambda$ *and between* $\mu$ *and* $\rho$, *the reading is DAY if the latitude is S, and the diagram fails to discriminate if the latitude is N; if* **T** *lies outside* $\lambda$ *and between* $\nu$ *and* $\rho$, *the reading is DAY if the latitude is N, and the diagram fails to discriminate if the latitude is S.*

7. *Accuracy of Dial.* The dial determines $n$ from equation (6). Inaccuracy in the determination of $SY$ will lead to an error in the derivation of $n$, and this error will be largest when $n = 6$. Denoting the correct value of $SY$ when $n = 6$ by $p$,

$$p = h\cos\delta. \tag{16}$$

If there is actually a small error $-p\epsilon_p$ in $SY$ when $n = 6$ (such as might be caused by small inaccuracies in the shape of the curved edge of the gnomon), the corresponding error $\epsilon_n$ in the value of $n$ indicated by the dial is given by putting $SY = p(1 - \epsilon_p)$ and $n = 6 + \epsilon_n$ in equation (6), whence

$$p(1 - \epsilon_p) = h\cos\delta\sin 15(6 + \epsilon_n)^\circ,$$

or

$$p(1 - \epsilon_p) = h\cos\delta\cos 15\epsilon_n{}^\circ. \tag{17}$$

From (16) and (17)

$$1 - \epsilon_p = 1 - {}^1/_2\{15\epsilon_n(\pi/180)\}^2 + O(\epsilon_n{}^4).$$

Hence

$$288\,\epsilon_p = (\pi\,\epsilon_n)^2, \tag{18}$$

ignoring terms of 4th and higher orders in $\epsilon_n$. Thus a small error of second order in $SY$ will cause an error of first order in $n$. For example, if $\epsilon_p = 0.01$, $\epsilon_n = \pm 0.540$ from (18), i.e. an error of 32 minutes in the indicated time, due to an error of $-1\%$ in $SY$.

When the point **Y** does not lie exactly on a line of the time scale, it is necessary to estimate the number of minutes past the hour from the position of **Y** in relation to the two lines of the time scale between which it lies. From noon to 4 p.m. this can be done to an accuracy of three minutes or better, but as the time approaches 6 p.m. this estimate becomes increasingly less accurate because the hour lines get closer together.

The dial therefore cannot be relied upon to give an accurate indication of the time near 6 p.m. (and, similarly, 6 a.m.). It may be remarked that the azimuth-independent dials listed in Section 1 possess a similar defect, but at noon instead of 6 a.m. and 6 p.m.

When **T** is so close to **G** as to be obscured by the curved edge of the gnomon (which happens near sunrise or sunset), it is necessary to regard **G** itself as the point **T** in order to obtain a reading, and this introduces a further error in the indicated time.

In p.m. tests with the model at latitudes 50°N and 54°N, in which $\delta$ varied between 6° and 23.5°, the results in Table I were obtained by comparing the

TABLE I

ACCURACY OF LOCAL APPARENT TIME DETERMINED USING MODEL SUNDIAL

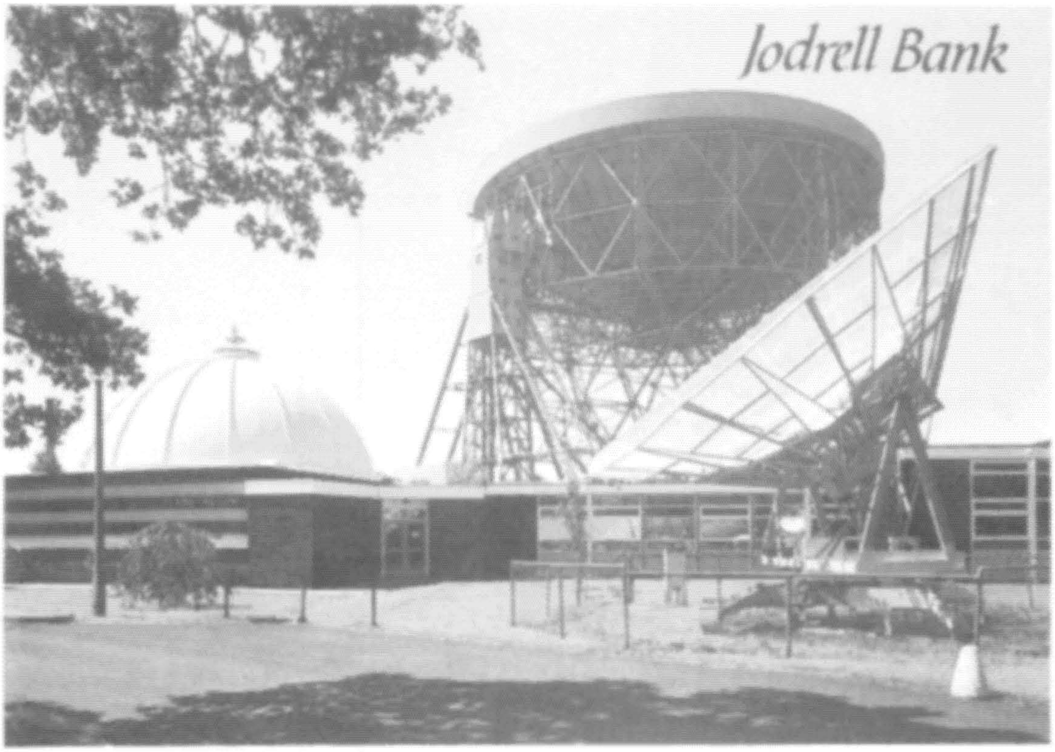
| Period (p.m.) | Number of Readings | Maximum Error (min) | Average Error (min) |
|---|---|---|---|
| Noon to 12:30 | 1 | 0 | 0.0 |
| 12:30 to 1 | 5 | 3 | 1.2 |
| 1 to 1:30 | 6 | 2 | 1.2 |
| 1:30 to 2 | 5 | 2 | 1.0 |
| 2 to 2:30 | 1 | 1 | 1.0 |
| 2:30 to 3 | 1 | 1 | 1.0 |
| 3 to 3:30 | 4 | 3 | 2.0 |
| 3:30 to 4 | 5 | 2 | 1.4 |
| 4 to 4:30 | 5 | 7 | 6.0 |
| 4:30 to 5 | 3 | 18 | 15.0 |
| 5 to 5:30 | 6 | 24 | 19.0 |
| 5:30 to 6 | 3 | 38 | 30.3 |
| 6 to 6:30 | 5 | 45 | 33.0 |
| 6:30 to 7 | 5 | 33 | 17.2 |
| 7 to 7:30 | 9 | 19 | 7.7 |
| 7:30 to 8 | 7 | 11 | 7.0 |
| 8 to 8:30 | 4 | 8 | 5.2 |

time indicated by the dial with the time indicated by a clock (due allowance having been made for longitude and the equation of time). In evaluating average errors the signs of the individual errors were ignored in order that positive and negative errors should not cancel each other out.

*Acknowledgments:* In conclusion the author wishes to express his thanks to Messrs. J. Merrick and J. Whitworth of the University of Bradford for their assitance with the production of the photograph and diagrams; also to the Editor of the Journal of the Royal Astronomical Society of Canada for giving permission for this article to be reproduced in this *Bulletin.*

First published in the J. Roy. Astron. Soc. Can., Vol. 72, No. 2, 1978. Another latitude-independent sundial has since been described by RIJK in the same Journal, Vol. 83, p.137, 1989.

# SUNDIALS AT JODRELL BANK




Since sundials have been included in the National Curriculum for Schools, the Jodrell Bank Science Centre which annually caters for thousands of schoolchildren, teachers and members of the public generally, have asked us for help and advice, both in their Teachers Resource Centre and in their public display areas, particularly in the Arboretum which is attached to the centre.

Andrew Somerville was approached some time ago and he headed a small deputation which had initial discussions at Jodrell Bank June 1990. More recently, following a further meeting, I put our specific proposals in writing, these proposals have been ratified by a meeting of our council and broadly accepted by Jodrell Bank. The proposals can be summarised as follows:

1. To help to provide a range of dials of different types to be sited in the Arboretum (or 'Tree Centre' as it is known at Jodrell Bank).
2. A number of larger demonstration dials to be designed and built giving 'hands on' experience to younger visitors.
3. Various demonstration models, books and information packs for teachers to be provided for the Resource Centre.

A committee has been formed to further this exciting project which includes Charles Aked, Anne Somerville, Dr. A.A. Mills, also a member of our Education Group and myself. The Education Group, chaired by Jane Walker will of course be actively involved in vital parts of this project.

Following some preliminary enquiries I have already had promises of dials from two of our members and plans for an analemmatic dial have been sent. A major display of dials could indeed be established at Jodrell Bank which could bring sundial enthusiasts from far and wide. I would appreciate any offers from members willing to donate a sundial, books, or demonstration equipment or who think they can help in any way. I understand that any such donation will be acknowledged in some way, ie by a suitable plaque next to the sundial, and/or mention in visitor's guides. If you are interested or want more information please let me hear from you.

*David Young*

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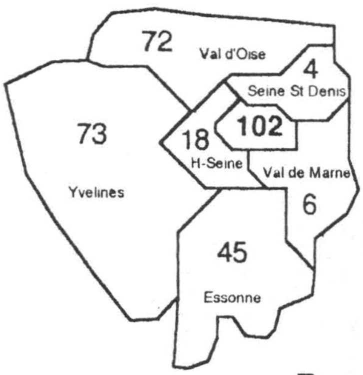
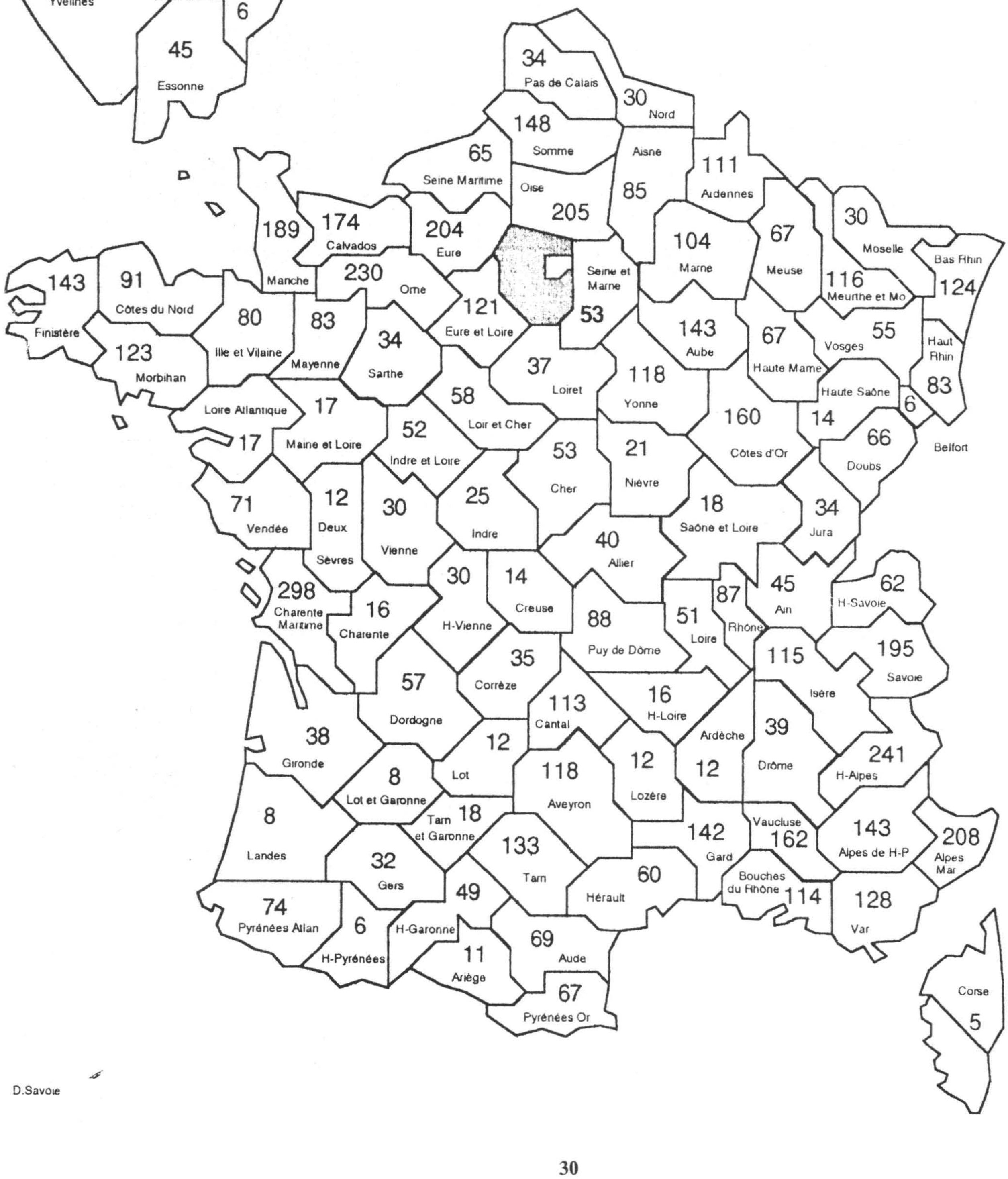
**SUBMISSIONS TO THE EDITOR:**

The Editor welcomes articles, letters, news items and photographs connected with the art and subject of dialling. If possible texts should be typewritten with double line spacing, photographs preferably black and white, and line drawings of a standard commensurate with that of the *Bulletin* as an important gnomonics journal. For further details please refer to page 2 of *Bulletin* 89.2. Texts in the Italian, German and French languages can be translated, but take time.

# DEPARTMENTAL DISTRIBUTION OF FRENCH SUNDIALS

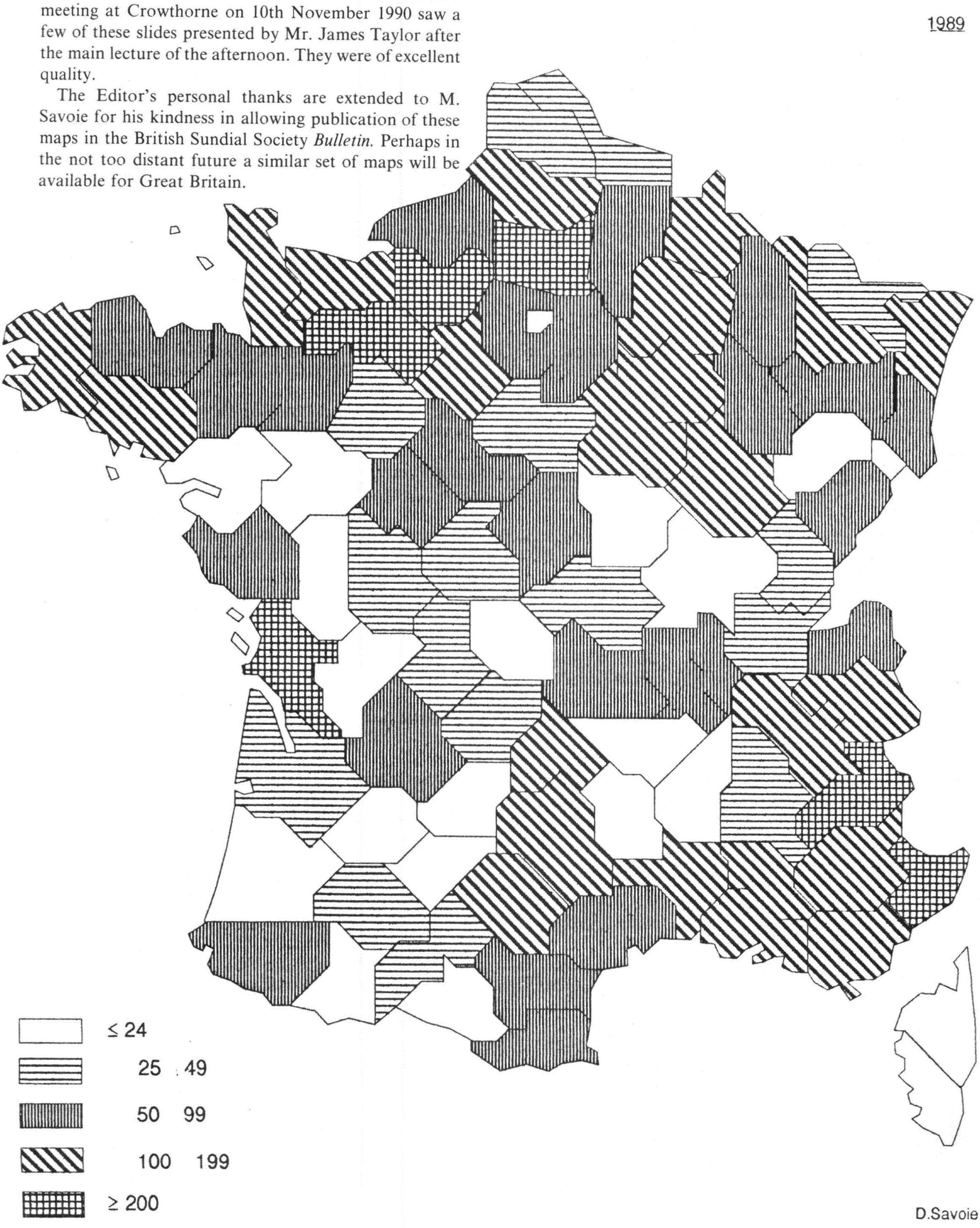
Permission has been obtained from the President of the Commission of Sundials, Paris, Monsieur D Savoie to reproduce the maps included here showing the distribution of sundials in the districts of France and Corsica. Because there are so many sundials in the Paris area, the distribution is given in the detached inset. The figures given are those known up to 31 December 1989, more are continually being added to the list. The details of these sundials are recorded on cards kept at the Société Astronomique Française in Paris. There is also a collection of transparencies [over 8,000] which record individual dials, formed by the previous President of the



Commission of Sundials, M. Sagot. This collection of slides has to be more comprehensively detailed, a formidable task. Those members who attended the BSS meeting at Crowthorne on 10th November 1990 saw a few of these slides presented by Mr. James Taylor after the main lecture of the afternoon. They were of excellent quality.

The Editor's personal thanks are extended to M. Savoie for his kindness in allowing publication of these maps in the British Sundial Society *Bulletin.* Perhaps in the not too distant future a similar set of maps will be available for Great Britain.



# A 'HUMAN' SUNDIAL

The centre-piece of the childrens' playground in East Chesterton Green Recreation Ground, Cambridge, is a 'human' sundial. A child, standing on the gnomonstone, sees his [or her] shadow cast among the hour-points - numbered tiles embedded in the pathway - and can read the time. The design is that of an analemmatic dial. It is constructed for use with a gnomon of about 4ft in height, ie. a junior school child or 'average age and height'. The hour points are numbered for the summer months and indicate British Summer Time. In accurate analemmatic dials, provision must be made for movement of the gnomon to correspond with the month of the year, but this sundial is designed for summer use only, with a single gnomon stone. The inscription [supplied by a local resident, Mrs Derry Earnshaw], reads:

STAND HERE TALL AS THE WORLD SPINS ROUND - SEE TIME'S SHADOW FALL SHOW THE HOUR ON THE GROUND

The stone, circular and slightly convex, of Portland stone with an insert of Westmorland slate, was carved by Harry Gray of The Carvers' Workshop, Cambridge.

Children from a nearby school, St Andrew's Junior School, helped in choosing the theme of the playground. They were interested in the study of stars, planets, outer space and other celestial matters; and so the play area was set up as a 'Playground of Planetary Proportions in which the toys, equipment and planting-groups are named after objects in the solar system. Close to the sundial is a climbing-frame 'Mercury'. A little further off is a see-saw 'Venus', and so on. The Asteroids are represented by a line of ornamental shrubs; the ring around 'Saturn' is a low circular bank planted with ground-cover bushes, and so on.

The whole project enjoyed user-participation from the outset, indeed some children from the St Andrew's School class of 1987/88 helped with the setting-out of the hour point tiles. The playground was set up in 1989-1990 by the City Council's Landscape Architects [Mr Douglas Rule and his team], in collaboration with the Senior Housing Estates project Officer, Mr Andy Buckley.

Fig 1 - Setting out the dial, Andy Buckley foreground left, centre Harry Gray

Fig 2 - A young lady of pre-school age shows how the sundial is used but her shadow is too short!

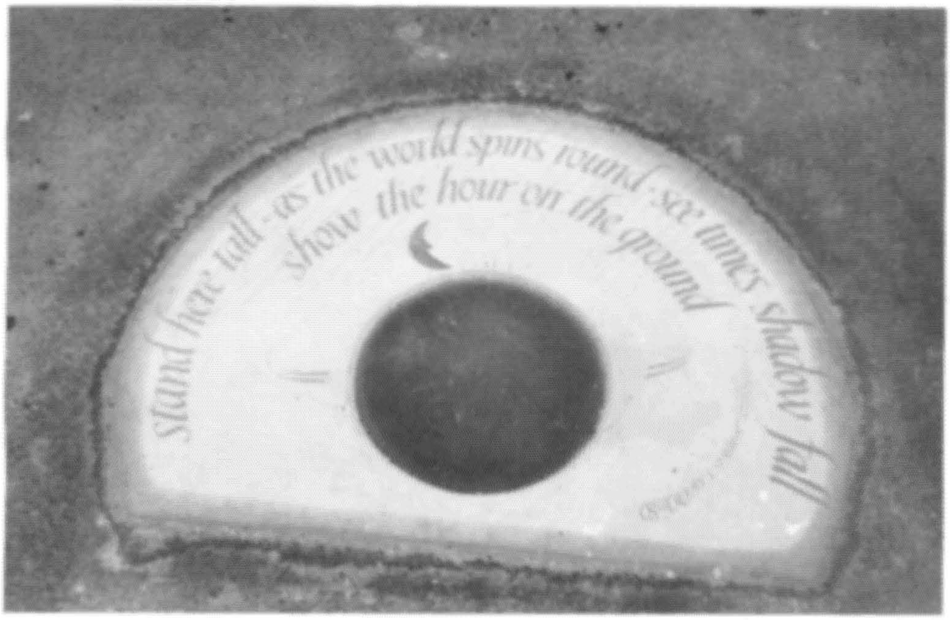


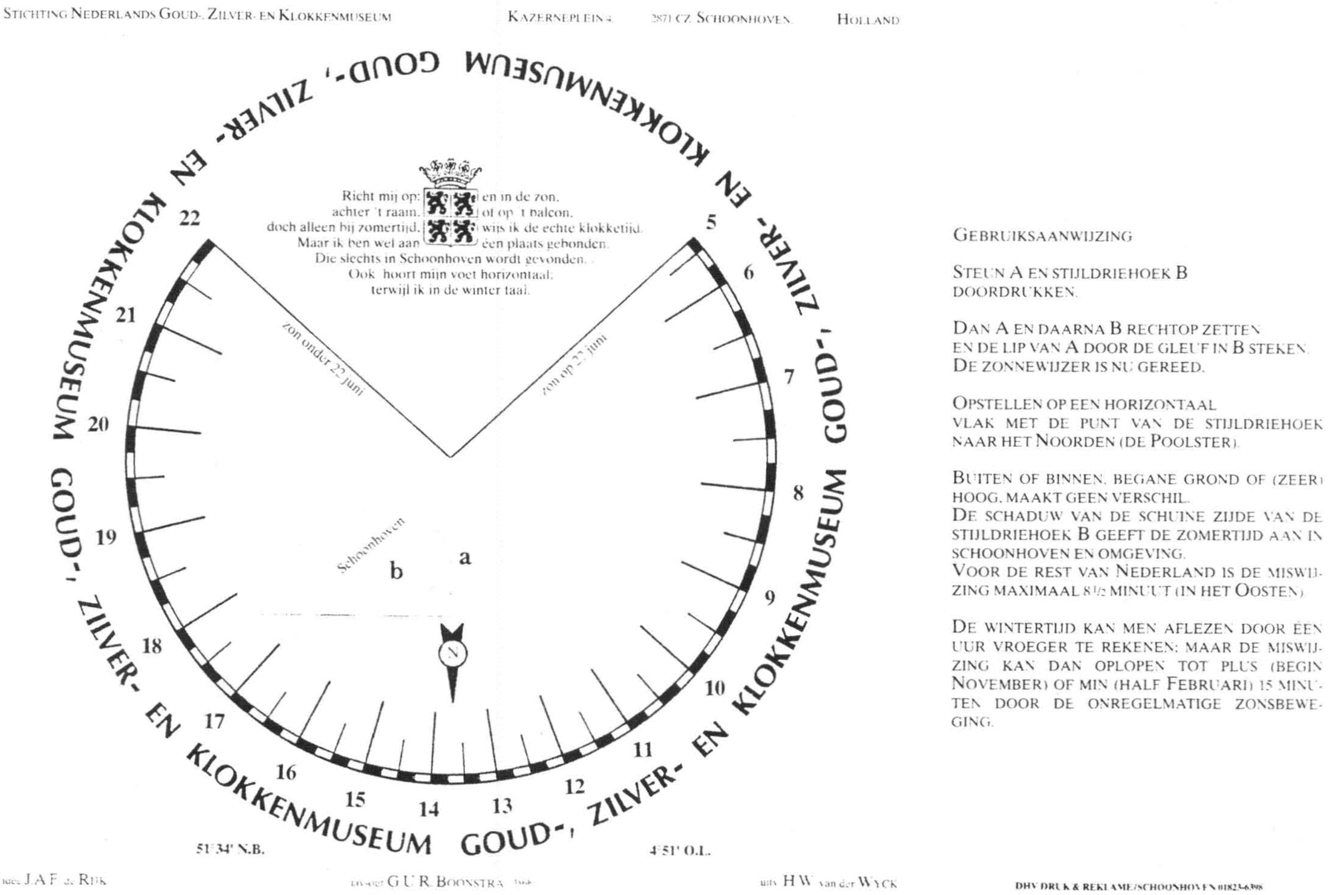

Fig 3 - The "Gnomon-Stone" with inscription - see text.

## SCHOONHOVEN GOLD - SILVER - AND CLOCK MUSEUM

This well known museum in Holland recently [1990] had a small exhibition which included some sundials, and notably a large instrument about a metre across which consisted of a circular row of lamps placed above a horizontal dial so that a visitor could press a button for any selected hour and see the correct shadow on the dial. There were many sundial photographs, including those on the Tower of the Winds, near the Parthenon, in Athens.

A souvenir of the exhibition was a small card on which was printed a horizontal sundial, with instructions for its use at the latitude of Schoonhoven - 51° 34′, the suggestion of J.A.F. de Rjik and the lay-out by G.U.R. Boonstra. An example of this was sent to the Editor by Mr. W.A. van Aken as a result of some correspondence on the Tower of the Winds sundials.

The card is illustrated here. Please do not ask the Editor to translate the Dutch instructions - he has lost his Dutch dictionary. These mention Summer and Winter-time, the fact that no part of the Netherlands will give an error more than $8\frac{1}{2}$ minutes indication on the dial, and the Equation of Time error; and on the dial itself the time of dawn and sunset on 22nd June - just over nineteen hours of sunlight! The latitude is almost that of London.




## GREENWICH MEETING

There will be a meeting at Greenwich Old Observatory commencing at 14.00 on 16th February 1991 to which all members of the British Sundial Society are invited. The BSS Council will be holding a meeting in the morning at Greenwich and will probably take lunch in the Maritime Museum restaurant, should any member wish to consult any one of them before the afternoon meeting. Members' wives may prefer to look round the Maritime Museum or the local shops. Please meet outside the Old Observatory main gate before 14.00 so that we may be in the Time Gallery by 14.00. There is, unfortunately, an admission fee of about £2.90, we may obtain a slight reduction as a group. For those travelling by car, it is best to enter the Museum grounds by the upper gate [where the London Marathon pours through] and park in the ample space provided near to the Old Observatory. Those intending to take part are invited to notify Mr Mike Cowham by letter or telephone [see back cover for address and telephone number], by letter or telephone [see back cover for address and telephone number], in order that the necessary arrangements may be made. Don't forget the dialling books may be obtained from Rogers Turner Ltd at 22 Nelson Road, Greenwich, quite near to the Museum.

# LETTERS TO THE EDITOR

## THE SPHERICAL SUNDIAL

The simplest and most perfect representation of the earth in its relation to the sun is the sphere held up and fixed by an inconspicuous support in a sunlit place. The sphere represents the earth, the shadow on the sphere in the form of a hemispherical cap, or calotte [French for skullcap], represents night; the unperceived movements of the sphere represent (and in fact are) the movements of the earth, rotation and orbital. The edge of the shadow represents the terminator, dawn on one side, sunset on the other. This is a splendid tool for teaching the elements of helio-geography to pupils. Peter Drinkwater is to be thanked for drawing it to our attention [*Bulletin* 90.3. page 12].

But its use as a sundial for indicating the time poses problems. In the left hand figure on page 13 the ray of the sun strikes the surface at the invisible 6 on the equatorial belt. It is noon and the time is, or should be, indicated by the terminator shadow cutting across the figure 12 on the west side of the dial. The dial would indicate the time all right but it would "feel" wrong. A French word for south is "midi" as we diallists feel appropriate. Teachers would have a very difficult task to explain to children why the number for noon is not directly in line with the sun at actual noon. "It would of course; but there would be no shadow to mark the time"... This and the fact that the terminator is not a clean edge of shadow but, appropriately a zone of twilight in the tangential rays of the sun, may explain why the sphere as a timepiece was abandoned and forgotten.

It deserves to be rediscovered as a superb teaching aid. I would go for simplicity: presenting natural facts without any human concepts such a numbered hours, longitudes and latitudes. It might be permitted to have a rough outline of the British Isles high on the sphere, facing south-wards and decorated by a tiny obelisk whose shadow at noon would indicate the line that the late nineteenth century became the zero reference line for longitude and times throughout the whole world.

*Yours sincerely,*
*G.P. Woodford,*
*30.10.1990*

## ORIENTATION OF WALL

Several years ago, whilst in the South of France, I acquired the card shown here; and the instructions are shown below (translated freely from the French).

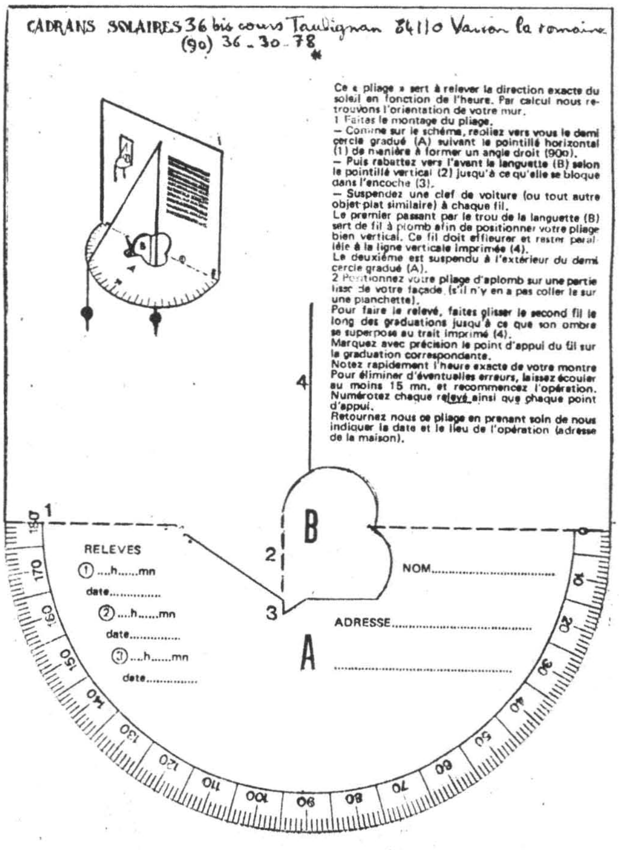
INSTRUCTIONS

To find the orientation of your wall this card is to be placed facing the sun.

Make up the card as shown in the drawing, folding the graduated semi-circle 'A' towards you on the dotted line (1) at a right angle, (90°). Then push out the tongue 'B' towards the front, folding down line (2) until it is held in the slot (3). Pass a thread through the hole marked * and allow one half to pass through the tongue space 'B', with the other is suspended on the outside of the graduated semi-circle 'A'. Suspend a car key or similar object on each line to act as plumb-lines, then place the card against your wall so that the printed line 'A' is vertical. To mark the hour line - slide the second plumb line along the graduations until its shadow falls vertically on the paper. Mark the shadow at the point you notice on the line on the corresponding graduation. Quickly note the exact angle shown. To eliminate errors, leave for at least 15 minutes and start the above operations again. Number exactly each point noted. Return to us this folding card and take care to indicate the date and the place of the operation [and house address].

Is it possible that one of our more mathematically inclined members could supply the formula for me to be able to ascertain the angle of a wall away from true South?

*Yours faithfully,*
*Richard Thorne,*
*28.8.1990*



**FILLING FOR SLATE DIALS:**

Before a visit from friends and dialling enthusiasts I fill in the letters and graduations of my slate sundial with French chalk to improve the contrast. Naturally this does not last very long in Irish weather conditions and I would be glad to hear from any reader who can recommend a filling which is permanent and weatherproof without affecting the dial irreversibly.

*Yours faithfully,*
*R.J. Shackleton,*
*3.11.90*

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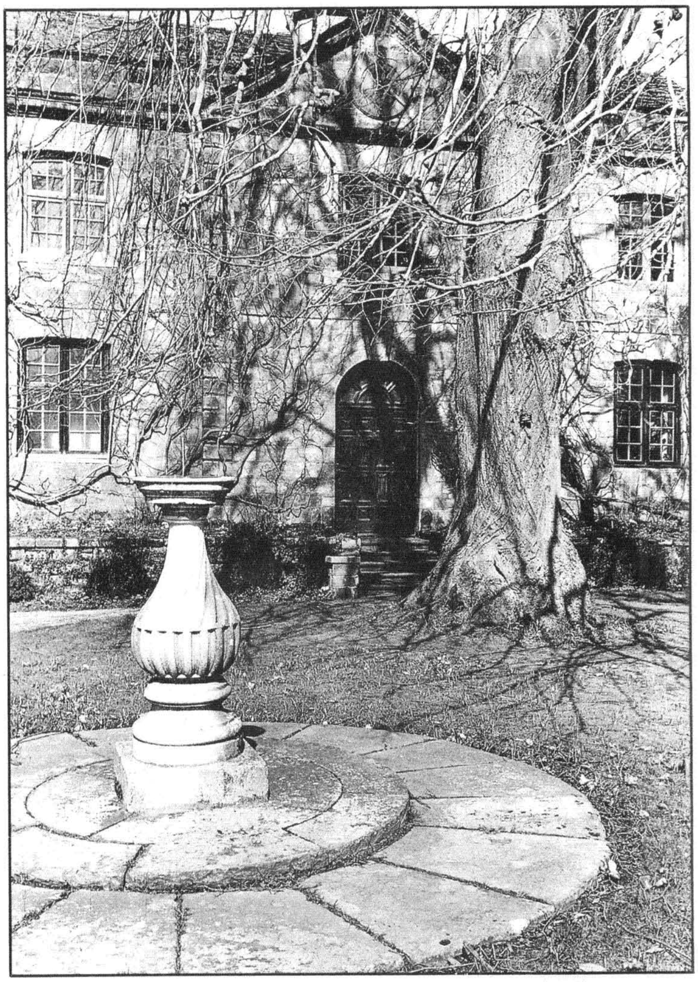
**SUNDIAL IN CARRIAGE RING, WAKEHURST PLACE**

Unusually here the clock in the pediment of the house is almost totally obscured, but the sundial on its fine pedestal has fortunately avoided the shadow cast by the intrusive tree. What folly allowed it to grow so near the foundations of the building?



# GREY DIAL STONE

T'is but an old dial, grey with many a stain
Sprinkled in Spring with the softest of rain,
In Summer crowned with wind-fallen bloom,
White-dressed in Winter, a cold marble tomb.

Round about its grey, time-weathered, brow,
Worn letters read - "A Shadow art Thou,
I too am a shadow but here mark the hour,
Do likewise you whilst thou still has the power".

Grey dial stone, what does thou know?
Of the thoughts of those who see thee and go,
Whose sadness writ deep is clear at a glance,
Eyes reddened with weeping, in sorrowful stance.

Lost in a world once seeming strong and secure,
Where Time was for ever and ever before
That moment that faces each mortal we know
That Fate has decreed a long time ago.

Grey dial stone, the dark shadow on Thee,
Reflects life's sad moments for both you and me,
How slowly your shadow moves in mournful decline
With sorrow writ large on your circular line.

Grey dial stone, it seemed clear to me,
That sunshine for ever would fall on thee,
But now that the clouds of departure loom near,
All will be darkness and sorrow I fear.

Grey dial stone, when next at dawn I arise,
Mark well the hours from when I open my eyes;
So that I too before my last day on earth,
Might measure my time as you have from birth.

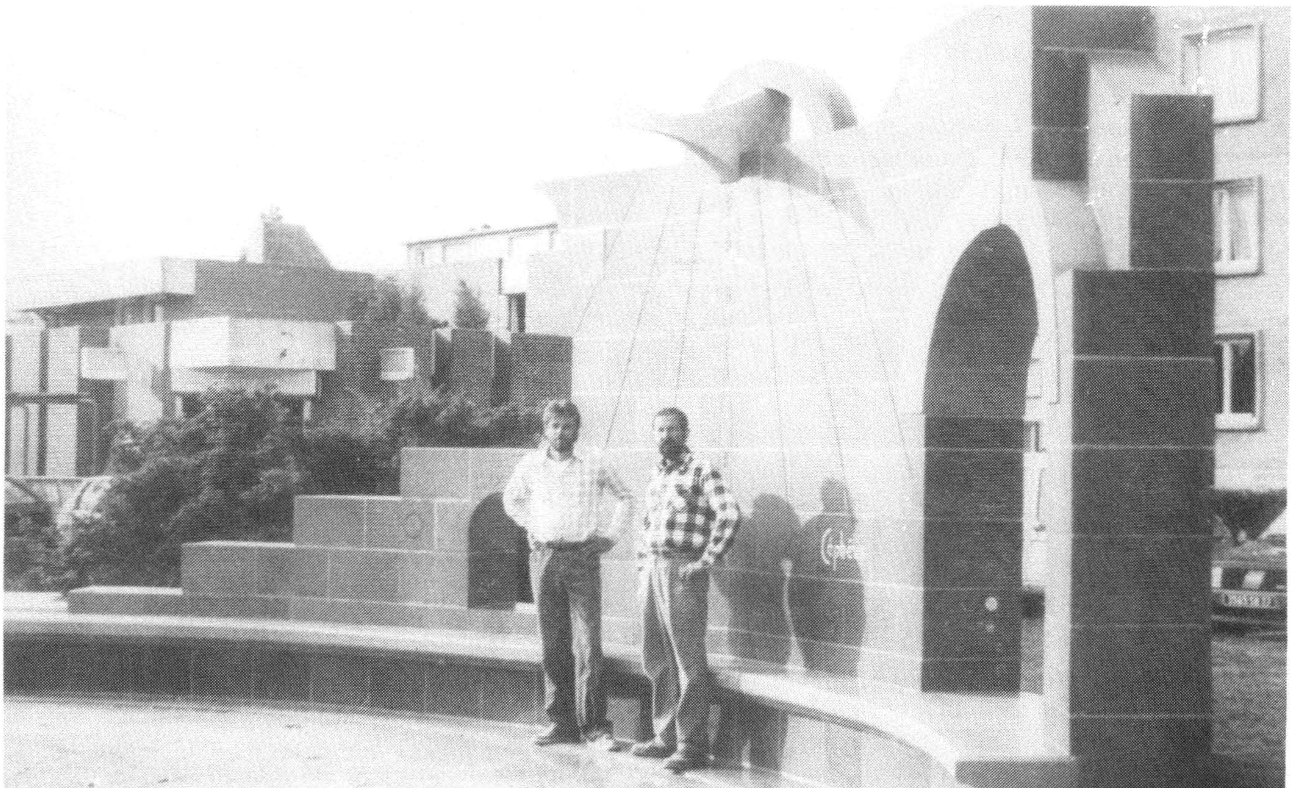
Full many a century have you shown the hour,
Subjected to weather and time's limitless power,
Yet many will see you long after I'm gone,
And your simple message will truly live on.

# THE SECRETARY'S NOTEBOOK

Many articles and announcements about the Society have appeared in a number of magazines and journals, which invariably lead to a flood of correspondence (over 60 letters from one article alone in a recent issue of 'Country Living' written by our member, Jades Driver). While some will be very welcome enquiries for membership, a great many have been queries of the type: "I have been given a present of a sundial, please can you tell me where to put it in my garden?" and "I want to put my sundial on a pedestal, can you tell me how high it should be?". Requests asking how to make a sundial are common and I recently had a batch from engineering students who had obviously been asked by their lecturer to make a sundial as part of their project!

Perhaps the most common letter received is the one asking where a sundial can be bought. The original list of makers I had was compiled when the society was formed and includes some non-members and some that have now gone out of business. Since my request in the last 'Bulletin' I have a good response and the new list will include brief details of the type of dial made and is composed of Society members only. I would be pleased to send this list to anyone who cares to send me a stamped addressed envelope.

Two letters I have received a little while back have caused a flurry of excitement. Both were requests to help restore a sundial and in each case members living locally have been a great help. A church dial in Gloucestershire with only the gnomon extant has been examined by our member Colin McVean who is working out the delineation of the hour lines. In the other case Mr G Stapleton brought our attention to a large and somewhat unique dial in Northamptonshire. Member, Pat Briggs has visited the site and taken some photographs which seems to indicate that all that is required is the replacement of the missing gnomon and a good clean up. As the dial is some twelve feet high and altogether a pretty massive object, I hope with the permission of the present owners to assemble a working party in the Spring to travel down to tackle the job. I hope it will be possible in a future article to tell the complete story of the restoration of these two dials.



**NOBLE SCIENCE**

One of the latest creations of the French firm of Noble Science - the helio-sculpture "Céphéus". The stonework is actually a warm golden brown in colour. Noble Science is the enterprise run by Claude Dupré and Jean-Michel Ansel of La Plardière, Charpgeneteux, F - 53160 BAIS, FRANCE; seen together here in front of their work. More details to be given in a future issue of the *Bulletin*.

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