

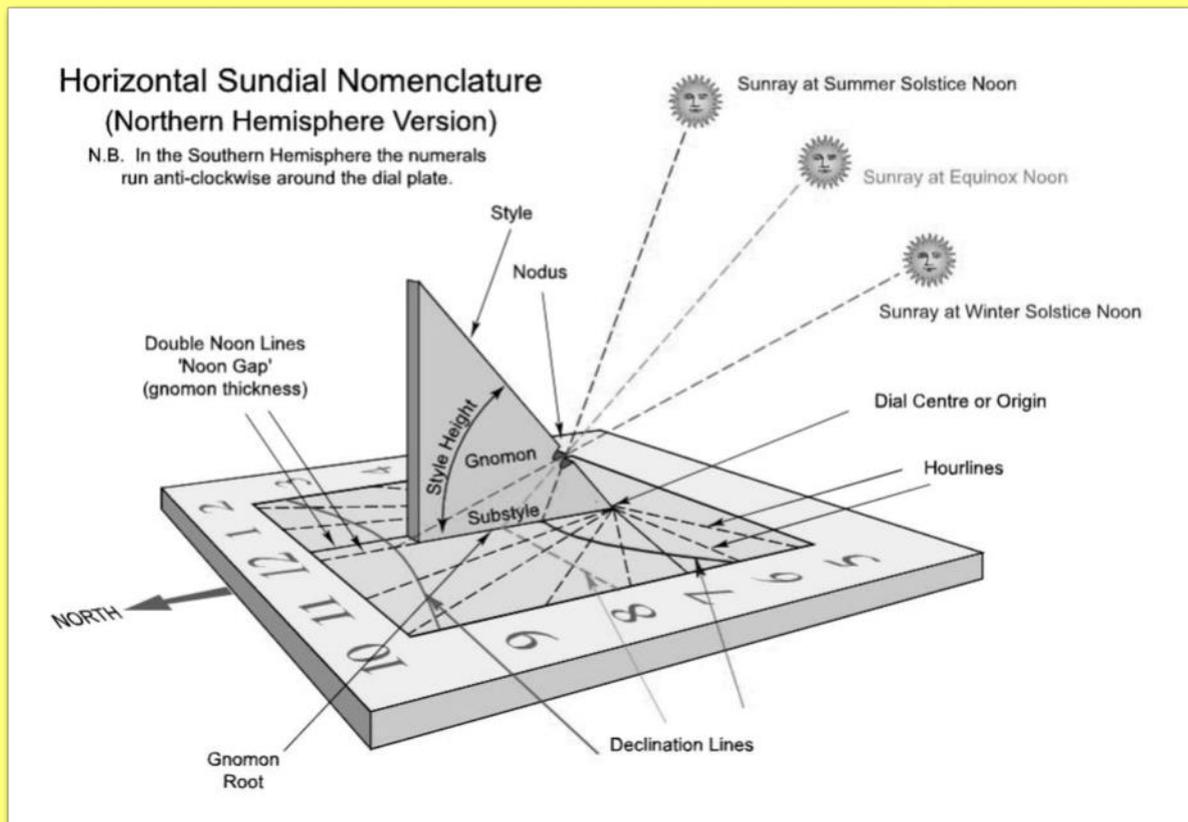
BSS SUNDIAL GLOSSARY

AND

SOURCEBOOK OF DIALLING DATA

Third Edition

Editor: John Davis



The British Sundial Society



BSS

Sundial Glossary

A sourcebook of dialling data

Second Edition

Editor: John Davis

Published by
The British Sundial Society
2004

Published by

The British Sundial Society
4, New Wokingham Road,
Crowthorne
Berks, RG45 7NR

© John Davis, 2000, 2004

Design and layout by John Davis
Printed and bound in Great Britain by
Colourplan Print and Design Ltd., Ipswich.

ISBN 0 9518404 6 0

All rights reserved.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without prior permission in writing of the Publisher, The British Sundial Society 2000, nor be otherwise circulated in any form of binding or cover other than that in which it is published and without similar condition including this condition being imposed on the subsequent purchaser

BSS

Sundial Glossary

A sourcebook of dialling data

Glossary: a list with explanations of abstruse, antiquated, dialectal or technical terms.

FORWARD TO THE SECOND EDITION

The first edition of the Glossary was well received but, naturally, many readers found omissions or inconsistencies in some of the entries. These have now hopefully been addressed, although a work like this will never be completed. The major areas added for this edition are a set of thumbnail biographies of the major players in the development of dialling, an expansion of the Equations section to include more dial types, and a major increase in the number of appendices providing solar and other data.

March 2004

PREFACE TO THE FIRST EDITION

Several letters to the BSS Bulletin in 1999 suggested that a sundialling glossary would be useful in furthering the Society's aims. It is hoped that this resulting glossary will fulfil two objectives. The first of these is to provide newcomers to dialling with a reference document which will explain the many strange terms or unusual usages of common words which they will come across in the dialling literature.

The second objective is to try to produce definitive meanings of the terms which diallists sometimes use rather loosely, and which can therefore lead to some confusion. Thus when several words have the same meaning, the preferred use is described here. Likewise, an attempt has been made to produce a standardised set of symbols for the most widely used terms in dialling equations.

Choices between different meanings have been made on the basis of adopting the most common modern usage found in the literature (particularly those items shown in the *Sources* section) as long as this does not produce confusion. Alternative usages, spellings or conventions which may be met, particularly in early dialling works, have been given where possible, but it is hoped that future authors will adopt the preferred definitions given here.

As English is used in countries other than the UK, there may be alternative definitions overseas. However, this glossary has been assembled with collaboration from the North American Sundial Society and, via the medium of the internet, diallists worldwide, so it is not expected that there will be major differences in terminology throughout the majority of the English-speaking world.

It is proposed to update this glossary periodically, so that it will develop along with the science of dialling. If you have any comments, corrections or additions, please inform the editor at john.davis@btinternet.com or at the address below.

John Davis
Orchard View, Tye Lane
Flowton,
Ipswich IP8 4LD
UK

May 2000

SCOPE

The glossary contains mainly terms which are directly related to dials and dialling. Additionally, excursions into the fields of astronomy, horology, optics and solar sciences have been made where it seems useful. Some comments on the history of dialling are made and various solar data are given in the appendices.

NOTATION

Words in *italics* refer to entries in this glossary or other internal references. In electronic versions they are in hypertext and may be followed by clicking on them.

Bold text indicates a definition.

~ indicates a repeat of the entry word.

Symbols in square brackets [x, X] give the preferred symbol and abbreviation. See section on *Symbols* for a full list.

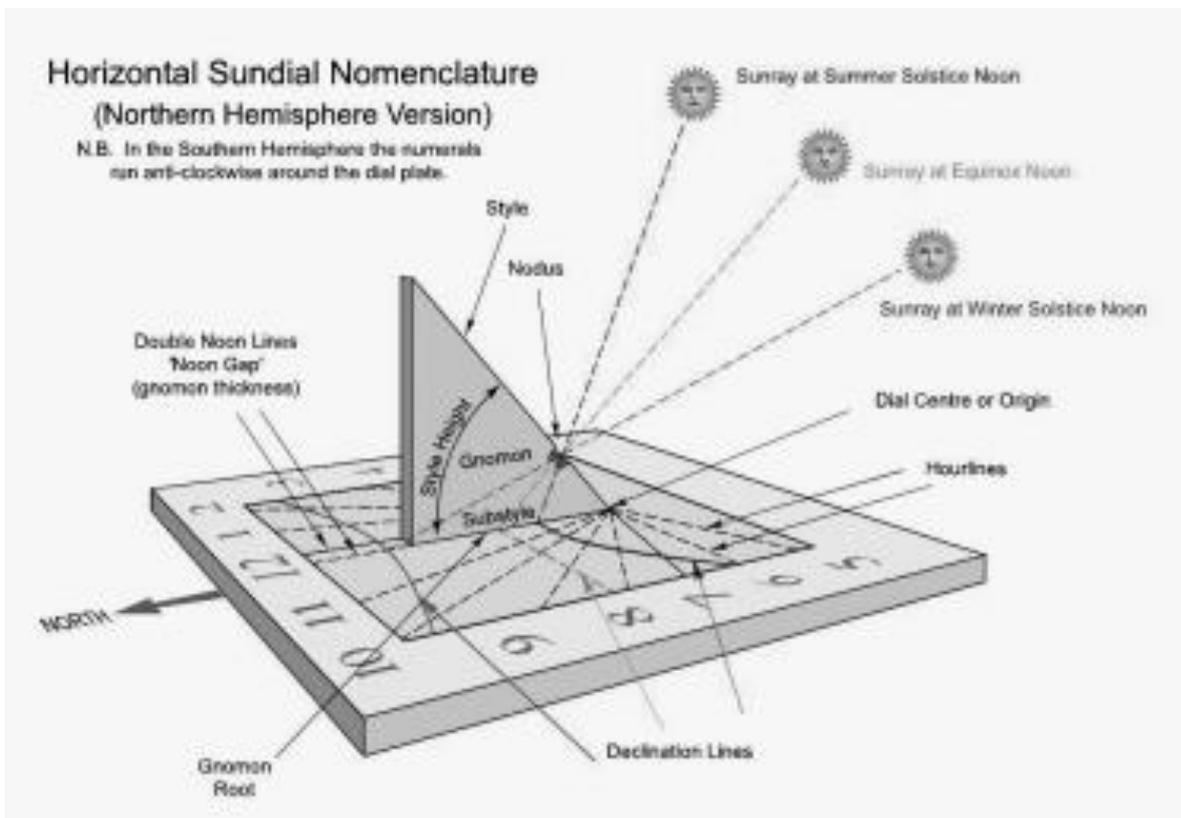
Alternative spellings or terms to the preferred ones are shown in brackets thus: {**dialing**}.

Pronunciation of unusual words is shown with a simplified phonetic scheme thus: **gnomon**: (pron. no-mon). If no pronunciation is given for an entry, it is pronounced as it is written (following normal Oxford Dictionary rules for English pronunciation).

ACKNOWLEDGEMENTS

I would like to thank the numerous members of the BSS and the NASS who helped with the definitions of terms, and who provided encouragement to the project. These include, in no particular order, Margaret Stanier, David Young, Patrick Powers, John Carmichael, Harvey Frey, Tony Wood, John Ingram, Doug Bateman, Frank and Rosie Evans, David Scott, Robert Terwilliger, Fer de Vries, Fred Sawyer, Gianni Ferrari, Tony Baigent, Chris Lusby Taylor, Mac Oglesby, Vit Planocka, Daniel Wenger, Gordon Taylor, Michael Lowne, Sara Schechner, Robert van Gent, Tony Moss, Allan Mills, Thibaud Taudin-Chabot, Gerald Stancey, Mike Cowham, Gloria Clifton, Peter Ransom, George Huxley, Chris Daniel, Jill Wilson, Mike Shaw, Michael Harley, Paul Zoller, Tony Belk.

A note on the Southern Hemisphere. This glossary has been written primarily for the Northern Hemisphere, since this is where the majority (but not all) of the BSS membership resides. For horizontal dials in the Southern Hemisphere the gnomons point to the S celestial pole, and the hour numbers run anti-clockwise rather than clockwise. The notation and equations used in the glossary are consistent as long as the sign conventions are followed, but the reader must mentally change N to S in the text.



CONTENTS

<i>Alphabetical, including:</i>	2
<i>Co-ordinate Systems</i>	5
<i>Days (types of)</i>	7
<i>Dial types</i>	8
<i>Hours (types of)</i>	22
<i>Time (types of)</i>	35
<i>Symbols</i>	38
<i>Equations</i>	40
<i>Biographies</i>	44
<i>Chronology</i>	56

Appendices

<i>I</i>	<i>Signs of the Zodiac</i>	62
<i>II</i>	<i>Anglo-Saxon tides</i>	62
<i>III</i>	<i>Roman Octaval system</i>	62
<i>IV</i>	<i>Canonical hours</i>	63
<i>V</i>	<i>Domifying lines</i>	63
<i>VI</i>	<i>Greek and Roman Seasonal Hours</i>	64
<i>VII</i>	<i>Architectural and Ecclesiastical terms used in dialling</i>	65
<i>VIII</i>	<i>Planetary hours symbols</i>	66
<i>IX</i>	<i>Magnetic variation</i>	67
<i>X</i>	<i>Astrolabe terms</i>	68
<i>XI</i>	<i>Ordnance Survey Grid</i>	69
<i>XII</i>	<i>Diallist's Calendar</i>	69
<i>XIII</i>	<i>Equation of Time</i>	70
<i>XIV</i>	<i>Sun's declination</i>	71
<i>XV</i>	<i>Sun's longitude</i>	72
<i>XVI</i>	<i>English Royal periods</i>	73
<i>XVII</i>	<i>Wall declinations</i>	74
<i>XVIII</i>	<i>Dates of adoption of GMT-based timezones</i>	75
<i>XIX</i>	<i>Forms of Numerals</i>	76
<i>XX</i>	<i>Japanese time reckoning before 1873</i>	77
<i>XXI</i>	<i>Climates</i>	78
<i>XXII</i>	<i>Wind and Compass Roses</i>	79
<i>XXIII</i>	<i>Calligraphy terms used in dialling</i>	79
<i>XXIV</i>	<i>Adoption dates for the Gregorian calendar</i>	79
<i>XXV</i>	<i>Altitudes</i>	80
<i>XXVI</i>	<i>Aspects</i>	80
<i>XXVII</i>	<i>Geometrical depiction of trigonometric functions</i>	81
<i>XXVIII</i>	<i>Terms used for imitation dials</i>	81
<i>XXIX</i>	<i>International Time Zones</i>	82
 <i>Sources</i>		 83
<i>Sundial Societies</i>		84

A

aberration (of light): the effect by which the apparent direction of distant astronomical bodies is altered by the velocity of the Earth and the finite speed of light. Discovered by *James Bradley*, it has a value of 20.47 arc-sec and is thus totally insignificant to dialling.

accuracy (of a dial): a measure of how closely the time indicators (lines or points) of a dial indicate the correct time. Contrast with *resolution*. See also *precision*.

Act of 1751: {1752} refers to an act of the British parliament in that year which finally adopted the *Gregorian calendar* and set the beginning of the (English) year to 1 January, rather than 25 March. As a result, there can be some confusion about the year, prior to 1752, for dates between January and March. Scotland's New Year's Day had already been set to 1 January since 1600. Dates in the Julian calendar are usually denoted 'Old Style', with those in the Gregorian 'New Style'.

British dials made before 1752 and which have *EoT* or *sunrise/sunset* tables show dates 10 or 11 days earlier than the current ones, e.g. the *vernal equinox* is on 10 March instead of 21 March, and the *EoT* will be shown as zero on 5 April, 3 June, 23 August and 15 December. Note that the Act was passed in 1751 but did not come into operation until the following year, hence the alternative dates sometimes seen.

acute angle: an angle of less than 90°.

AD: see *anno domini*.

age of the moon: see *phase of the moon*.

agonic line: a contour line of zero *magnetic variation*, linking locations where a *gnomon* may truly point to the magnetic pole. It is a special case of an *isogonic line*.

Alfonsine tables: tables of planetary positions, based on Ptolemy's theories, produced by the polyglot King Alfonso X ('the wise') of Castile in the mid-thirteenth century. They had diverged substantially from reality by the time of *Copernicus* and were declared 'worthless' by *Regiomontanus*.

alidade: the revolving arm of, for example, an *astrolabe* through which sightings of the stars are made. Sometimes used on sundials where a pinhole at one end of the ~ forms an image of the sun on a plate at the other end carrying an *analemma*.

almanac: {or *almanack* - archaic} an annual calendar of months and days, with astronomical and other data. They usually include an *ephemeris* of the sun and some other celestial bodies, the *equation of time*, the *sun's declination* etc. Almanacs are sometimes inscribed on, or accompany, 16th-18th century dials. The annual *Nautical Almanac*, now produced by the HM *Nautical Almanac Office*, derives from the version first published by *Astronomer Royal Nevil Maskelyne* in 1767. The word ~ has Arabic origins.

almucantar: (pron. al-moo-can-tar) a circle of equal *altitude* on the *celestial sphere*. It is a *small circle* on the celestial sphere, parallel to the *horizon*.

altazimuth: {alt-azimuth} a mounting system for an astronomical instrument that allows it to be set in *altitude* and *azimuth*. The term is also used to describe the *horizon co-ordinate system* which uses these two parameters.

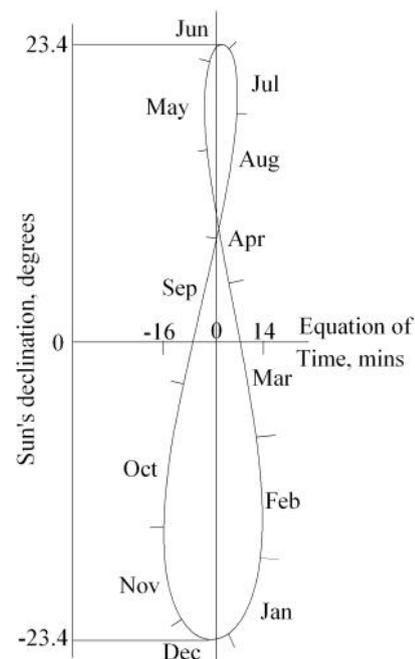
altitude (of the sun): {elevation} [a, ALT] the angular distance of the (centre of) the sun's disk above the observer's *horizon* (negative values indicate that the sun is below the horizon). It is measured along the *principal plane* to the sun's centre, and is the complement to the *zenith distance*. It is part of the *horizon co-ordinate system*. Note that aviators and others use the term *altitude* to measure a height (distance) above the ground. It is usually expressed in degrees but old dials used shadow lengths in multiples of the vertical *gnomon height* - see *Appendix XXV*.

amplitude occasive: a 17th century term for the sun's *azimuth* at *sunset*.

amplitude ortive: a 17th century term for the sun's *azimuth* at *sunrise*.

anaphoric (clock): a clock with a dial face like an *astrolabe*, showing *seasonal hours*.

analemma: (pron. ana-lem-a) in modern usage it is a graphical plot with the *Equation of Time* on one axis and the sun's *declination* on the other. In appearance, a tall thin figure of eight. The dates of various points around the curve are often shown. The shadow of a point falling onto an arbitrary plane at the same *clock time* each day will trace out an *analemma* over the course of a year. Normally seen on the *noon line* of a dial, but can be on any *hour line*. The exact appearance of the analemma will depend on the plane upon which it is projected. The term 'true analemma' is sometimes used for the version projected onto a sphere, e.g. on a globe.



The word *analemma* has had several other meanings in the history of astronomy and dialling. In the first century BC, the Roman engineer *Vitruvius* used the word to refer to a graphical construction, equivalent to today's *orthographic* projection. In the second century AD *Ptolemy* used ~ to mean an instrument acting as a *nomograph* for defining the angles of a dial. The use of a modern ~ on a dial dates to around 1640 and the first treatment in English was by *Samuel Foster* in 1654.

angle: (units of measurement) may be decimal *degrees*; degrees, *arc-minutes* and *arc-seconds*; *radians* (2π radians = 360°); or (seldom, military equipment) *mils* (6400 mils = 360°); or (very rare) *grade* ($1/100^{\text{th}}$ of a right angle). Preferred notations are: [dd.dd° or dd° mm' ss"]. The Latin for degree is "gradus" hence the abbreviation G is often found on 16th-18th century dials. Note that trigonometric functions in computer spreadsheets (e.g. Excel™) are always defined in radians. The mathematical convention is that positive angles are measured counter-clockwise, usually with the zero angle position in the 3 o'clock direction or along the x-axis (see *cartesian co-ordinates*). In dialling, it is more common to measure angles from the *noon line* with the a.m. hours positive. Some authors measure from the *sub-style* line.

anno domini: (Latin) 'in the year of our Lord', used in abbreviated form (AD) to distinguish dates from BC (before Christ). The introduction of the term is attributed to *Bede*.

Antarctic Circle: the parallel of *latitude* at $66^\circ 34'$ S. This defines the northern limit of the region around the S pole having at least one day a year with no night.

ante meridiem (a.m.): before *noon*. Latin.

antisolar point: the point on the *celestial sphere* directly opposite the sun's position.

aperture: a small transparent hole in an opaque surface, designed to let a small beam of *sunlight* through to fall on a *dial plate* or *alidade* e.g. for *noon dials*, *ring dials* and *heliocronometers*. The diameter of the aperture for a *meridian line* in a medieval cathedral was traditionally $1/1000^{\text{th}}$ of its height above the line. Sometimes called an *oculus*.

aphelion: (pron. ap-heel-eon) the point where the Earth's *orbit* takes it furthest from the sun. It occurs during the first week of July.

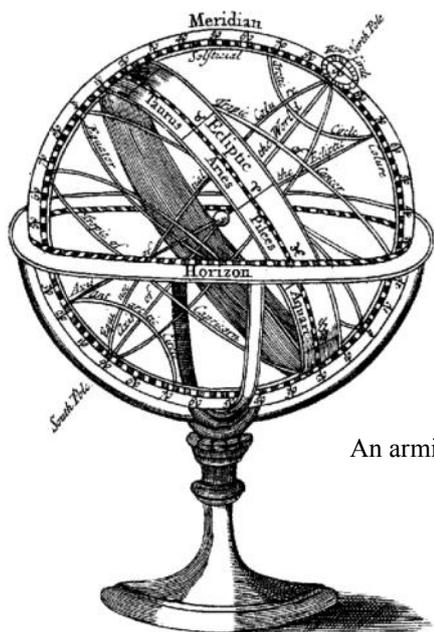
apogee: (pron. apo-gee) the point in the moon's (or other satellite's) orbit when it is furthest from the Earth.

arc: a curve which is part of the circumference of a circle.

arc-minutes {or **minutes of arc**}: an angular measure equal to $1/60^{\text{th}}$ of a *degree*. Preferred notation [' or arcmin].

arc-seconds: {or **seconds of arc**} an angular measure equal to $1/60^{\text{th}}$ of an *arc-minute*. Preferred notation [" or arc-sec].

Arctic Circle: parallel of *latitude* at $66^\circ 34'$ N.



An armillary sphere

Note that this defines the southern limit

of the region around the N pole having at least one day a year with no night.

Aries (first point of): see *equinoxes*.

armillary sphere: a skeleton model of the celestial sphere with rings representing the equator, tropics etc. Often finely made in brass, but versions in wood with paper scales were common in 19th century France. It was known in both China and the Hellenistic world by the 2nd century AD, and existed in both measurement and demonstration forms. It is also the basis of a form of dial - see *armillary*, dial (types of).

ascendant: rising towards the *zenith*. Note: astrologers have a different definition.

aspect: the angular separation (in celestial longitude) of two celestial bodies. The difference in celestial latitude is ignored. Used by astrologers - see *Appendix XXVI* for the terms used.

aspectarium: an aide-memoire which depicts astrologically significant angles (or *aspects*) between *planets*.

asterism: (a) a prominent group of stars, smaller than a constellation, having a popular name - e.g. the 'Big Dipper' in the constellation Ursa Major..

(b) a group of three asterisks in a triangle, sometimes used to mark the half- or quarter-hours on a dial.

astro compass: see *solar compass*.

astroid: (pron. as-troy-d) a mathematical curve which is formed by the envelope of a series of straight lines. It has the equation: $x = a \cdot \cos^3 \theta$, $y = a \cdot \sin^3 \theta$. In dialling, it is the shape of a vertical gnomon used in the latitude-independent *astroid* dial. The astroid curve is one branch of the shape which is traced out by a point on the circumference of a circle as it rolls inside another circle of four times the radius.

astrolabe: an early astronomical instrument in the form of a heavy disk (the *mater*) which was suspended vertically and had an angular scale marked around it (the *limb*). A coplanar *kimate* and an *alidade* rotated about its centre. A fretted *rete* gave the positions of the brightest fixed stars. The various components were held on the central pivot (the pin or axis) by a small wedge or horse; sometimes dog.

The **planispheric** ~ represents the *celestial sphere* by a two-dimensional *stereographic projection*, showing the position of the sun and major stars at different times and dates, as well as different latitudes. A separate plate is required for each latitude. It was probably a Greek invention of the 2nd century BC, but it was developed extensively by the Islamic cultures from the 9th century AD. It fell out of use in the late 17th century in the west. **Universal** astrolabes use modified projections of the celestial sphere so that they are latitude-independent. The Gemma Frisius type (developed in the west in the early 16th century) retains the stereographic projection but moves the centre to the *First point of Aries*. The **Rojas type** (by J. de Rojas of Sarmiento, 1550) uses an *orthographic projection* with a projection point at infinity. The **La Hire** type (late 17th century) moved the projection point to a point outside the celestial sphere in an attempt to make it easier to read. The **mariner's** ~ is a much-simplified instrument designed to measure the sun's altitude, using an open frame and weighted at the bottom to make it more stable

onboard ship; it is a precursor to the sextant. Its first recorded use is in 1481. See *Appendix X* for further astrolabe terminology.

astronomical triangle: the spherical triangle on the *celestial sphere* whose vertices are the observer's *zenith*, the elevated *celestial pole*, and the position of the sun (or other celestial body). Also called the *polar triangle*.

atmospheric refraction: see *refraction*.

autumnal {fall} equinox: see *equinoxes*.

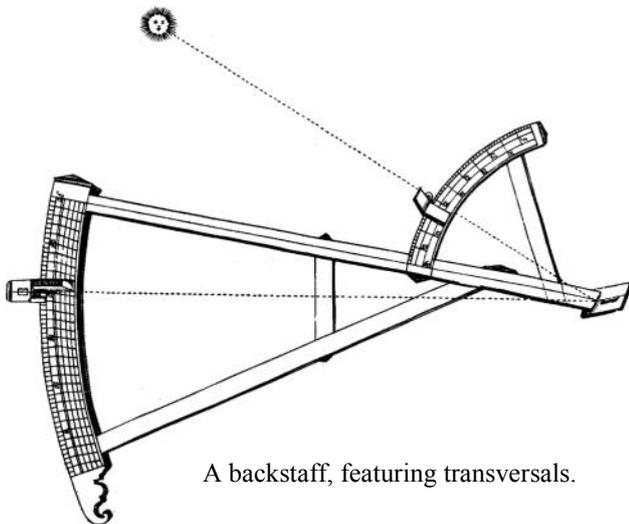
axis (of the Earth's rotation) or polar axis: the line running through the true North and South *poles* about which the Earth rotates.

azimuth (of the sun): [A, AZ] the angle of the sun, measured in the horizontal plane and from true south. Angles to the west are positive, those to the east, negative. Thus due west is 90°, north is ±180°, east -90°. It is part of the *horizon co-ordinate system*. Note that navigators (and some astronomers, but not *Meeus*) measure azimuth or bearings clockwise from the north.

B

back-staff: an old instrument for measuring the *altitude* of the sun while facing away from it. The **Davis quadrant**, designed by the English captain John Davis in 1595, is actually a form of back-staff.

bay: {bay en imy wenut} literally a 'palm rib of the observer of the hours'. It was an ancient Egyptian instrument or sighting device, used in conjunction with a *merkhet* to observe and time *transits*.



A backstaff, featuring transversals.

bearing: a compass direction, measured (usually in degrees) clockwise from the North (e.g. E is 90° and W is 270°). See *Equations 15* to calculate the bearing between two locations.

Beltane: {Beltaine} an ancient Celtic festival held on the 1st of May, when bonfires were lit. It is one of the *cross-quarter days*.

bissextile: a *leap-year* (from the Latin 'bis sextus dies', or doubled 24 February).

blue moon: there are at least two possible meanings. It can indicate a second full moon in a given calendar month. It seems that this 'meaning' was accidentally invented by Sky and Telescope magazine in 1946, but

it has passed into wide usage. Alternatively, it may mean that the moon actually has a blue colouration, due to smoke or other aerosols in the Earth's atmosphere. Both phenomena are rare (the second more so), hence the expression 'once in a blue moon'.

brachiolus: (pron. brak-e-o-lus) from the Latin for 'little arm', it is the articulated arm which acts as a suspension point for a cord on a *card dial*.

break of day: see *daybreak*.

British Summer Time: [BST] see *time (types of)*.

C

calendar: a system for counting days and defining the *date*.

Campbell-Stokes: see *sunshine recorder*.

Cancer: see *tropics*.

Candlemas: the festival of the purification of the Virgin Mary, on 2nd February. It also corresponds to the Celtic festival of *Imbolic* and is a *cross-quarter day*.

canting out: see *wedging out*.

Capricorn: see *tropics*.

cardinal point (of the compass): North, South, East or West [N, S, E or W]. These points are the intersections of the celestial meridian (N, S) and the prime vertical (E, W) with the *horizon*. Note that the Latin terms are Septentrio, Meridies, Oriens and Occidens, so that a compass rose on an early dial simply identifying 'S' is ambiguous.

cartesian co-ordinates: see *co-ordinates*.

celestial equator: the intersection of the extended plane of the Earth's *equator* with the *celestial sphere*.

celestial latitude: see *ecliptic latitude*.

celestial longitude: see *ecliptic longitude*.

celestial pole: the points on the Earth's *axis* where it meets the *celestial sphere*. The stars appear to rotate around these poles.

celestial sphere: an imaginary sphere, arbitrarily large and co-centred with the Earth, on which all the stars appear to be fixed.

centre (of a dial): the point where all the *hour lines*, and a polar-pointing *style*, meet. This point does not always exist (e.g. on *polar dials* and *direct E or W dials*, the lines meet at infinity). In simple *horizontal* or *vertical dials*, this point coincides with the "toe" of a (thin) *gnomon*. In the case of a thick *gnomon* having two styles, there are two centres to the dial. The centre is often, but not necessarily, the *origin* of the co-ordinate system used to describe the dial. The centre of the dial delineation need not necessarily be in the physical centre of the dialplate.

chapter ring: the ring on a dial face carrying the hour numerals. The term is more widely used for clocks, but it also finds use, for example, on dials with several separate rings for different locations.

chilindrum: see *Dial (types of)*; *cylinder ~*.

chronogram: {chronogramma} a phrase or sentence etc., usually in Latin, in which certain letters are highlighted. These letters represent Roman numerals which, when added together, form a number. A ~ is sometimes used to show the date of a dial within its motto, for example:

MIHI DEVS LVX ET SALVS gives 1627.

civil time: see *Time (types of) civil*~.

clepsammia: a sand-clock (Greco-Roman).

clepsydra: a water-clock (Greco-Roman). Literally 'stolen water'.

climate: a division of the Earth's globe into zones of *latitude*. In Classical times, the divisions were roughly equivalent to the tropics, temperate zones and arctic/antarctic circles and were expressed as the ratio of the longest to shortest daylight lengths. In the 17th and 18th centuries, the climates were defined such that there was a difference of half an hour in the length of the longest day at adjacent boundaries. See *Appendix XXI* for more details. The word ~ has, of course, become synonymous with the meteorological conditions in these regions.

clinometer: an instrument for measuring the *inclination* or slope of a surface. Also called an *inclinometer*.

cloisonné: (pron. klwo-son-ay) a term sometimes used to describe the technique of making metal dials by deeply etching the lines and numerals and then filling them with coloured material. It derives from the jewellery method of separating enamels into shallow compartments with metal edges.

cock: a 17th century term for a *style* or *gnomon*, particularly on *Butterfield dials*. Named from the likeness to a bird's tail. The term is also used for a part of a watch or clock, holding the bearing for the pendulum or balance wheel.

co-latitude: equal to 90° - *latitude*.

colure: (archaic) a *great circle* on the *celestial sphere* that passes through the north and south *celestial poles*. See also *equinoctial colure*.

compass bowl: a bowl sunk into the *dial plate* of a (portable) *horizontal dial* to house a magnetic compass.

compass rose: a drawing of the compass directions, showing as a bare minimum the *cardinal points*, but more usually eight, sixteen or all thirty-two *points*. See *Appendix XXII*.

compendium: normally used to describe a collection of

in-
in



an

con-

range of geometric curves produced by the intersection of plane with a cone (i.e. circles, *ellipses*, *parabolas* and *hyperbolas*). The first detailed study was by *Apollo-nius*.

contingent line: see *tangent line*.

contrast (of a shadow): a function of the light intensities

scientific instruments one case. Also, **Compendium:** the journal of the NASS. **complement (of angle):** equal to (90° - angle). **ic section:** any of the

in the shadowed and directly sunlit areas of a view. Several different versions are defined mathematically. The maximum possible value (1.0 for the definition of $(I_{\max} - I_{\min})/I_{\max}$) occurs when there is no *skylight*). The best practical contrast is produced by a matt white surface.

copy (of a dial): a reproduction of a dial designed to be as close to the original as possible. It should be clearly marked with its maker and the date if it is not to be regarded as a *fake*. cf. *replica* and *facsimile*. See *Appendix XXVIII*.

co-ordinates: a system of measurements used to describe any point in two or three dimensions.

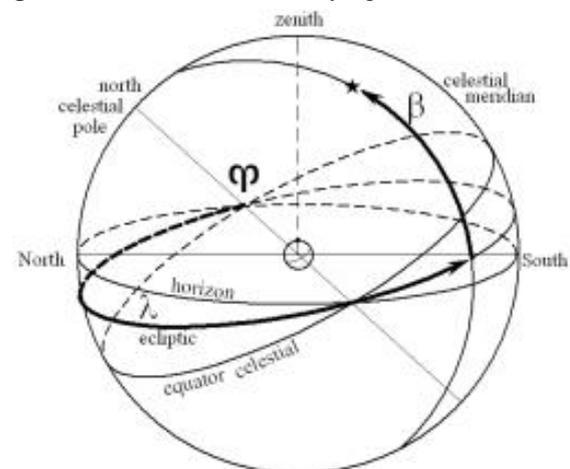
Co-ordinate Systems:

Cartesian ~ [x,y,z] in which the axes are mutually perpendicular, are normally used for positions of points within a dial. For simple *horizontal dials* the preferred axes have x increasing to the E of the *dial plane*, y increasing to the N of the dial plane and z (in 3-D only) increasing perpendicularly to the dial plane (upwards). For vertical and other plane dials, x increases to the left, y increases downwards, and z perpendicular to the plane in the direction towards the observer. The *origin* of the system must be defined explicitly. Note that these definitions produce a conventional right-handed co-ordinate system, and are also those used by the *Zonwvlak* programs.

ecliptic ~: {celestial ~} [β, λ_e] or [ELAT, ELON] the system of ecliptic (or celestial) *latitude* and *longitude*, defined with respect to the *ecliptic* and the *celestial poles*. Ecliptic co-ordinates predominated in Western astronomy until the Renaissance but, with the advent of national nautical *almanacs*, the *equatorial system* which is more suited to observation and navigation, gained ascendancy.

equatorial ~: [α, δ] or [RA, DEC] is the most common astronomical co-ordinate system and is defined by the *celestial equator* and *poles*. The *right ascension* and *declination* are directly analogous to terrestrial *latitude* and *longitude*.

galactic ~: is used for studying the structure of the

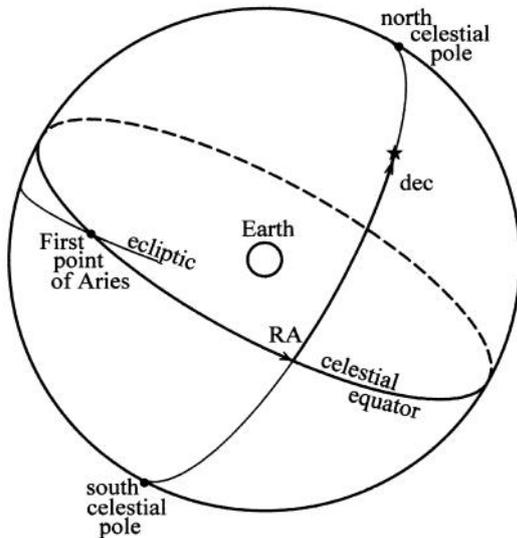


The ecliptic (celestial) coordinates as seen by an observer in mid-northern latitudes.

galaxy. It is unlikely to be encountered in dialling.

geographic ~: (or terrestrial ~) [ϕ, λ] or [Lat, LON] the standard method of determining any location on the Earth's globe, using *latitude* and *longitude*.

horizon ~ system: {or *altazimuth* system} [a, A] or



The equatorial co-ordinate system showing the right ascension (RA) and declination (dec) of a star.

[ALT,AZ] the simplest celestial co-ordinate system, it is based on *altitude* and *azimuth*. It is fundamental in navigation as well as in terrestrial surveying. However, for specifying the position of the sun or other celestial bodies, other co-ordinate systems fixed with respect to the *celestial sphere* are far more suitable.

Ordnance Survey co-ordinates: (also referred to as the British National Grid, BNG) the system of Eastings and Northings used to define locations in the UK. They are *cartesian co-ordinates* with a basic grid consisting of 100km squares, each of which has a unique two-letter code (e.g. SZ). See *Appendix XI* for a map of the grid squares. The full OS grid reference comprises these two letters followed by a three-digit easting and a three digit northing, eg SZeennn. This gives a resolution of 100m in both directions. Higher resolution ('6-figure' or BNG) references usually replace the letter code with their numerical values, eg eeeeeee nnnnnn, giving a 1m resolution. Here, the first two digits of the easting (northing) are the distance in 10 km increments east (north) of the datum point at the bottom left of the map. The OS maps on which the co-ordinates are based use the transverse *Mercator* projection, with a projection origin at 49° N; 2° W (i.e. just beyond Land's End).

polar ~: [r, θ] an angle-based co-ordinate system sometimes used for defining points on a dial plane, where r is the distance from the origin and θ is measured anti-clockwise from the S. Note: navigators also make use of polar co-ordinates and usually define them as (θ, r) .

Ptolemaic co-ordinates: [hec, hor] an angular co-

ordinate system loosely based on the geometry of *Ptolemy*.

terrestrial: see *geographic* ~.

- **End of Co-ordinate systems** -

cosine rule: the relationship in spherical trigonometry which connects the key angles of the *spherical triangle*. See *Equations*. Originally devised in the 9th century by *Albategnius* (also called Al-Battani)

crepuscular: (adjective) of the twilight, e.g. crepuscular rays seen on clouds after *sunset*. The noun *crepusculum* was used for twilight in the 17th century. The Latin label '*linea crepusculi*' is sometimes found on the line on an *astrolabe* denoting an *altitude* of -18°. In modern speech ~ is also used for the sun's rays shining through gaps in clouds (at any time of day).

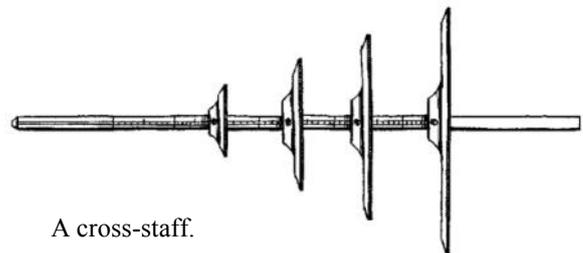
cross: for a discussion of the cross sometimes seen on the noon line of a dial, see *noon cross* and *cross patty*.

cross patty: {c. *pattée* or c. *formée*} an heraldic term for a form of square cross shape (☒) sometimes seen instead of XII on the *noon line* of dials. It is perhaps the most common of the *noon crosses*.

cross-quarter days: days which are (approximately) midway between the *Quarter days*, hence dividing the year into eight parts. They are occasionally used instead of the *zodiac* signs for *declination lines* on dials, and have become adopted as modern celebrations or holidays. See *Appendix XII* for their names and dates.

cross-staff: a simple instrument for determining the *altitude* of a celestial body. A cross piece or *transom* is moved along a staff, calibrated with a cotangent scale, and sighted by eye against the body and the *horizon*. Old illustrations often show a ~ with three or four transoms fitted but, in use, only one would be used at a time. Also called a **fore-staff** or **Jacob's staff**.

culmination (of the sun): the moment when the sun (or other celestial body) reaches its highest *altitude* (or this position on the *celestial sphere*) in its *diurnal* path. For bodies with a fixed declination, it is the same as the *superior transit*. For the sun and the moon, there is a



A cross-staff.

very small difference between the times of culmination and transit which is neglected in all but the highest precision astronomical or navigational calculations. From the Latin '*culmen*', meaning summit.

cursor: a pointer or index line of a mathematical instrument which slides backwards and forwards over a scale.

cusp: (mathematical) a sharp point where two curves meet e.g. the 'horns' of the moon (strictly, where the second derivative of a curve changes sign).

(astrological) the initial point of an astrological *house* or *sign*.

cycloid: (pron. si-cloy-d) a geometric curve which is traced out by a point on the circumference of a circular disk rolling (without slipping) along a straight line.

D

daeg mael: one of the Anglo-Saxon *tides*, it may also have been the word for a dial in the early Anglo-Saxon period.

dagsmork: an Icelandic term ('daymarks') referring to landmarks in the countryside which, when viewed from a fixed location, indicated the direction of the sun at fixed times of the day.

date: a single day in a chosen *calendar* system. Note that the agreed international date system (and British Standard 4795) specify 'year, month, day' - for example 1951 August 10. Common UK usage is the reverse of this - beware the illogical American usage of month, day, year, especially in all-numeric forms.

Date Line: see *International Date Line*.

dawn: the first light of day, taken as the onset of morning *twilight*.

day: the period for one (approx.) rotation of the Earth. Various types of day may be defined, as below. Beware the possible confusion between day and *daytime*. In 17th century dialling literature, 'days' is sometimes spelled 'daies'.

Day (types of)

cross-quarter ~: see *cross-quarter day*.

mean solar ~: measured between successive *transits* of the fictitious mean sun. Equal to 24 hours, it is the usual meaning of 'day' unless it is further qualified.

natural ~: an old (e.g. 17th and 18th century) term for a solar day, often found on dials in expressions such as 'Æquations of the Natural Days'.

pendulum ~: a *mean solar day*. Used in the 17th century to distinguish between clock (mean) and solar days.

quarter ~: see *Quarter days*.

rectifying ~: a 17th century term for certain days in the year when a clock would be adjusted to allow it to show solar time, to within a specified accuracy. For example, 10 rectifying days in a year would allow a clock to remain within 1/16th of an hour of true solar time.

solar ~: measured between successive *transits* of the true sun.

sidereal ~: used by astronomers and measured between successive transits of the *First point of Aries* (or, in everyday language, any 'fixed' star). A sidereal day is 23 hours 56 minutes 4.1seconds of mean solar time and is the time for the Earth to complete one rotation in space.

- End of Day (types of) -

daybreak (or **break of day**): an old term for first light, usually taken as the onset of astronomical *twilight* in the morning.

day letter: see *dominical letter*.

daytime: that period of a day between *sunrise* and *sun-*

set.

Daylight Saving Time: see *time (types of)*.

declination (of a wall): {sometimes called the **declining angle** or the **deviation**, to avoid confusion with the *sun's declination*} [*d*, **DEC**] the angle, measured in a horizontal plane, that a wall's perpendicular makes with due south (i.e. a wall facing S has $d = 0^\circ$). Walls declining westward have positive declinations, those eastward, negative. Beware - this is not a universal convention and some authors define the angle with respect to the nearest *cardinal point* of the compass.

declination (of the sun): [**δ**, **DELTA**, **DEC**] the angular distance of the sun above or below the *celestial equator*. Its value follows an annual sine wave like curve, varying between 0° at the *equinoxes* and $\pm 23.4^\circ$ (approx.) at the *solstices*. It has positive values when the sun is above the celestial equator (summer in the Northern hemisphere) and negative when below. The same system is used as part of the *equatorial co-ordinate system* (together with *right ascension*) to locate other celestial bodies. See *Appendix XIV* for values throughout the year.

declination lines: lines on a dial showing the sun's *declination* on a particular date. They are read by observing the shadow of a *nodus*. The shapes of the ~ on a flat plane are *conic sections*, most usually *hyperbolae* for typical dials in the UK. The solstice line(s) are straight and perpendicular to the *sub-style line*.

declinatory: {**declinator**} an instrument used (typically in the 17th century) for measuring and plotting *inclined* or *declined* planes. It consisted of a graduated semi-circle. The more modern term is declinator.

degree: [$^\circ$ or deg] an *angle* equal to $1/360^{\text{th}}$ of a complete circle. Originally from the Latin "*gradus*", hence on 16th-18th century dials the abbreviation G is often found.

descendant: falling from the *zenith*. Note: astrologers have a different definition.

descensivus circle: (archaic) a *great circle* on the *celestial sphere*, used by the ancients and by *Ptolemy* to define the position of the sun. It passed through the *zenith*, the *nadir* and the sun. Ptolemy measured the **descensivus angle** along this circle, from the zenith to the sun; it is thus the modern *zenith distance*.

deviation: a term used by some authors for the *declination of a wall*, in an attempt to avoid confusion with the sun's declination. However, it may then be confused with *magnetic deviation*.

diagonal scale: {**transversals**} a device for interpolating between scale divisions, pre-dating the *vernier* scale. It is constructed by drawing diagonals between individual divisions across a wide band, with a series of equi-spaced arcs parallel to the main scale crossing them. It is read by noting the position of the *fiducial line* with one of these arcs. Most usually found on astronomical instruments, a similar design was used by *Sir Christopher Wren* for indicating the minutes on his famous vertical dial on All Souls' College, Oxford.

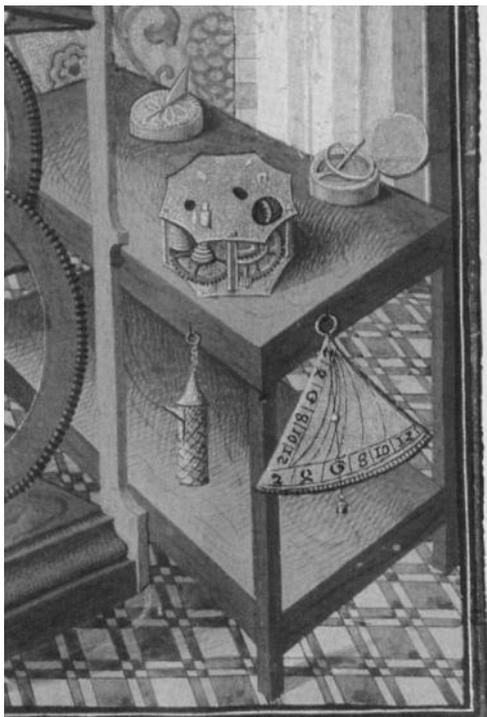
dial: a Middle English word, apparently deriving from the Latin 'dies' though the medieval Latin 'dialis', used for what is now called a *sundial*. It later became used for many types of indicators, hence the necessity (from

1599) for the qualifying ‘sun’ prefix. . In 17th century dialling literature it is sometimes written as ‘dial(l)’. The word ~ in modern English has now become common again as a shortened version of sundial. Hence **dialling** {dialing}, the art and science of designing and constructing dials; **diallist** {dialist}, one who designs or makes dials. The -l- spelling is common in America.

Dial types:

Ahaz (Dial of Ahaz): supposed *refraction dial*, from the Bible story (Kings 20 v.8-11) which may allude to a dial showing time running backwards.

altitude ~: {or elevation ~} any dial which uses the



Details from a 15th century manuscript showing horizontal, universal equinoctial and shepherd's dials, as well as an 'old' quadrant and a clock mechanism.

sun's *altitude*, rather than its *azimuth*, for indicating the time. Usually does not need to be aligned N-S. Examples are *ring dials*, *flag dials*, and *shepherds' dials*. Altitude dials were also often incorporated in *quadrants* and *folding rules*.

analemmatic ~: (pron. ana-lem-mat-ic) a dial consisting of *hour points*, (rather than lines) laid round an *ellipse*, and a movable *gnomon* perpendicular to the *dial plane*. It may be on any plane, but the most usual form is horizontal. In the horizontal version of the dial, the gnomon position lies on the straight N-S minor axis, at a point determined by the *sun's declination* (i.e., the date). Most usually found set in the ground in parks, where the observer acts as the gnomon. Note that some of these dials show an *analemma* drawn about the gnomon positioning line. This is a method of indicating the *EoT* for the appropriate date, but it must be remembered that the gnomon is not positioned on the analemma. The analemmatic dial may be regarded as a projection of the *universal*

equatorial ring dial. Analemmatic dials were once common paired with a horizontal ~ in a self-orienting portable *compendium*; some authors refer to this combination simply as a portable analemmatic dial.

analemmic ~: this term has sometimes been used to describe dials which have an *analemma*-shaped *gnomon*, or analemmas on the *hour lines*, enabling them to read *mean time*. The type in the form of an equatorial dial with a solid gnomon formed by revolving the analemma was patented by Major-General John Ryder Oliver in 1892. Note, the dials have no direct link to *analemmatic* ones.

Anglo-Saxon ~: {sometimes just **Saxon ~}** a sundial from the Anglo-Saxon period (c 650 – 1050 AD); designed to show *unequal hours*, or the basic *tides*, with a horizontal *gnomon*. Similar to the *mass dials* which superseded it, a Saxon ~ shows much higher levels of craftsmanship and is often finely decorated. Also, it is invariably engraved in a separate (circular or rectangular) stone, not into a pre-existing wall. Saxon dials are often taken to be the precursors to the later *scientific* dials. In the early part of the period the semicircle was divided by five lines into four segments. During the latter part of the period it was subdivided into eight or twelve segments and the dial sometimes carried an inscription in Old English. Throughout the period the principal lines had a cross bar near the perimeter giving the appearance of Latin crosses. See *Appendix II* for the basic time periods shown on the dial.

antiboreum: an ancient form of dial, mentioned by *Vitruvius* and with the shadow-receiving surface facing north. Always found in association with a dial facing south, it is a form of *conus*.

Apian ~: a *card dial* which is a universal form of *capuchin ~*, in appearance very similar to the *Regio-montanus ~*. Developed by *Peter Apian* around 1533.

arachne ~: {arachnen or conarachnen} a ~ described by *Vitruvius*, who attributes it to *Apollonius* or Eudoxus of Knidos. So named because the lines look like a spider's web.

armillary: (pron. ar-mil-ar-y) (or armillary dial; some authors also use the term *armillary sphere*) a form of *equinoctial* sundial which comprises, as a minimum, two circular bands plus a rod through the poles representing the Earth's *axis* and acting as the *gnomon*. One band represents the *equator* (carrying the hour scale) and the other the local *meridian*. Usually, other *great circles* are added representing the *Prime meridian* and the *ecliptic plane*, sometimes together with small circles for the *tropics* and *arctic circles*. These add artistically, but detract from its clarity as a dial. The gnomon sometimes carries a *nodus* at the centre of the sphere; this may be used for indicating the date.

astroid ~: a ~ which uses the *sun's declination*, *altitude* and *azimuth* to give the *hour angle*. It is latitude-independent, and is named after the geometric *shape* which forms its gnomon.

astronomical ring ~: a ~ developed by *Gemma*

Frisius in 1557 as a simplified version of the armillary sphere. It is similar to the *universal equinoctial ring* ~ which it pre-dates. It has an inner third ring carrying an *alidade* for measuring the altitude of a star instead of the bridge. This third ring is calibrated with the sun's *declination*.

Augsburg ~: a style of portable dial made around Augsburg, Germany, during the late 17th and 18th centuries. They usually took the form of small *standing ring dial*, often with an octagonal base, and were highly decorated.

aux-

me-
to
ing
oth-



An astronomical ring dial.

(particularly *vertical decliners*) by co-mounting on a common *gnomon* and projecting the *hour lines*. Often used with a *trigon*.

azimuthal ~: (**azimuth** ~) a class of dial which uses the sun's *azimuth* for indicating the time. It usually needs to be aligned N-S, and has a vertical style (if it has no dependence on altitude).

Benoy ~: see *refraction* ~.

Berossos ~: another term for a *hemicyclium*, named after its inventor Berossus Chaldaeus, a Babylonian astronomer who flourished on the Greek island of Cos around 270 B.C.

bifilar ~: invented in 1922 by Hugo Michnik in its horizontal form, although it can be on any plane. The time is indicated by the intersection on the dial plate of the shadows of two wires (or other lines in space) stretched above and parallel to it. The wires often run E-W and N-S, with their (different) heights above the plane being a function of the location of the dial. It may have equiangular markings, and hence can be delineated to show many kinds of hours.

bish-
dial,
pendant
with
holes
for a
above
Some-



op's ~: an early form of *altitude* usually in the form of a metal

A bishop's or Canterbury dial.

horizontal peg to be inserted time scales for various dates. times called a Canterbury ~.

~: see *polyhedral* ~.

Bloud ~: a portable, *magnetic azimuth* ~ made mostly in Dieppe by makers such as *Charles Bloud*.

iliary ~: a small *equatorial dial* used as a chanical aid construct-dials on er planes

They only work correctly when the *magnetic variation* is zero and hence often have a date around 1666.

book ~: {**open book** ~} a modification of the *polar* ~, with the *dial plate* consisting of two planes set in a vee, with their intersection line lying parallel to the Earth's *axis*. A *polar gnomon* can be placed bisecting the angle of the two planes. Alternatively it may be arranged so that the outer edge of each plane acts as the *gnomon* for the other. The term *book* ~ can also be applied to *diptych dials* which are designed to look like a book when closed.

bowstring ~: a name sometimes applied to the "C-ring" form of *equatorial dial*, with the thin rod *gnomon* looking like the string of a bow.

Butterfield ~: a pocket sundial by, or in the style of, *Michael Butterfield* (Paris, 17th century). Typically, it consists of an octagonal silver *horizontal dial* with a *gnomon* of adjustable angle, often with a bird's head pointer, with several rings of *hour lines* for cities of different *latitudes*. A magnetic compass is sunk into the dial plate.

cannon ~: see *noon gun*.

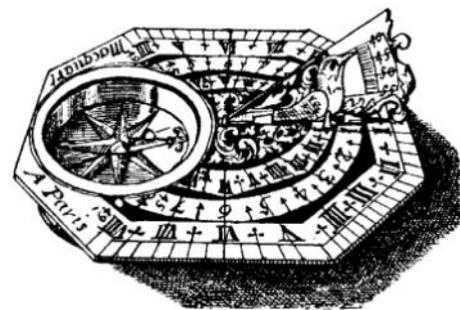
Canterbury ~: see *bishop's dial*.

Capuchin ~: {or **Capucine** ~} a latitude-specific *card dial*, related to the *Regiomontanus dial*. So-called because the outline of the hour-lines is said to resemble a hooded Capuchin monk. The earliest known picture of the design is in Sebastian Münster's "Horologigraphia" of 1533.

card ~: a class of *portable dials* built on a single plane, e.g. a card which is suspended in the vertical plane. They usually have a sun sighting device along the top edge, and a cord with a bead which hangs vertically below a movable suspension point.

CD ~: see *diffraction* ~.

ceil-
ing
~:



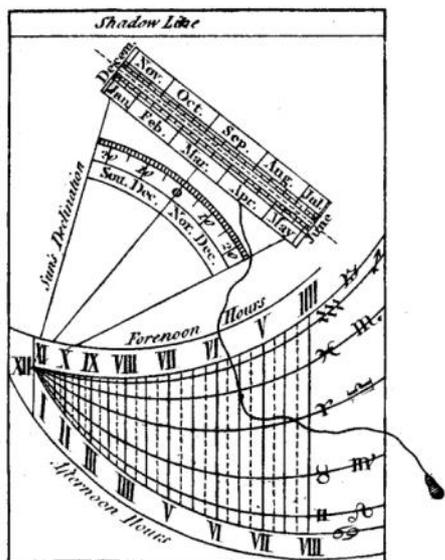
A Butterfield dial with adjustable bird's head gnomon.

{also known as a **mirror** ~ or **reflected** ~ or **spot** ~} a dial marked on a ceiling where the time and sometimes the date are indicated by a beam of sunlight reflected from a small horizontal mirror placed on a windowsill. It was first described in 1646 by *Kircher*.

chalice ~: (or **cup**, **bowl** etc.) a form of *refraction* ~ where the hourlines are drawn on the inside of a drinking vessel. Some are delineated so that they only read correctly when filled with a liquid of known *refractive index*. Early examples, often in

precious metals, are rare and valuable.

Chinese ~: a wide range of dials have been used in China, from the vertical gnomon of the mythical as-



A Capuchin dial, one of the card dials.

tronomer Xi, through *equiangular* ~ with sun-pointers and 100-segment time scales from the 1st - 2nd centuries BC, *equatorial dials* for equal hours in the Ming dynasty (1368 to 1664), to conventional horizontal dials in the 19th century.

compass ~: a *portable* horizontal dial with an accompanying compass to allow it to be correctly oriented. The compass is often below the pierced dial plate, and the gnomon is hinged for packing. Beware: the term compass dial is often used to mean a *magnetic dial*.

complementary ~: a (hypothetical) horizontal ~ used as an aid to designing a vertical declining and/or reclining dial. Its *gnomon* and *hour lines* are calculated not for the site of the proposed (real) dial, but for the location where the Earth's surface is parallel to the *dial plate* of the proposed dial. For a simple *direct south* dial, the complementary dial would be located at the *co-latitude*.



A chalice dial.

ed not for the site of the proposed (real) dial, but for the location where the Earth's surface is parallel to the *dial plate* of the proposed dial. For a simple *direct south* dial, the complementary dial would be located at the *co-latitude*.

cone ~: a term used to describe at least two entirely different types of dial. (a) a class of dials where the *dial plate* is an inverted, truncated cone, giving dials similar to a *scaphe dial* or a *hemicyclium* and attributed to Apollonius of Perga in around 250 BC. This is the **conus** of *Vitruvius*, who attributed it to

Dionysodorus of Caunus at the end of the third century BC. (b) a class of modern dials which use a cone lying on its side as the *gnomon*. Many varieties, including *sidereal*, exist.

crecent ~: a ~ in which the usual circular hour ring is replaced by two semi-circles placed back to back.

cross ~: (or **cruciform** ~ or **crucifix** ~) (a) a dial in the form of a cross, usually of stone, with the 'front' surface of the cross parallel to the *equatorial plane*, and the top pointing south. The side surfaces of the cross can each form a *dial plane*, with their *gnomons* being a corresponding edge of the cross itself. Usually found as churchyard memorials. Uncommon.

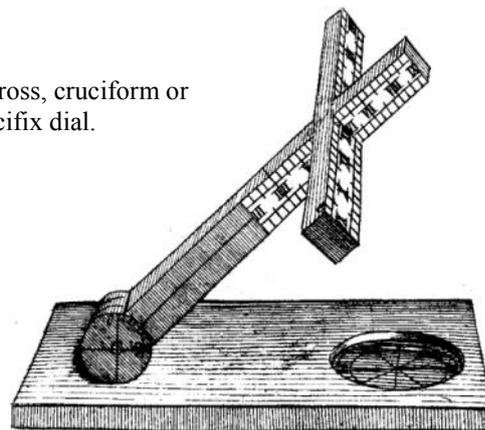
Portable crucifix dials usually have the long arm parallel to the *polar axis* and the short arm E-W. (b) A second form acts as a portable altitude dial with the cross-piece set vertically and the hours marked along the sides of the long arm.

cube ~: a (set of) dials on the surfaces of a cube. There may be up to 6 dials, but more often 5 e.g. direct N, S, E, and W, together with a *horizontal* on the top surface. Alternatively, it is possible to set the cube so that its top surface is parallel to the *equatorial plane*, i.e. the base makes an angle equal to the

co-

A cross, cruciform or crucifix dial.

latitude with the *horizontal*

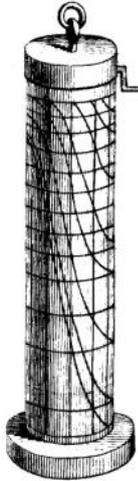


zonal. Both portable (usually adjustable) and monumental versions are known.

cycloid (polar) ~: a variation of the standard *polar dial* in which the gnomon has a *cycloid* shape, with the result that the *hour lines* are equally spaced.

cylinder ~: (also known as a **shepherd's** ~ or **pillar** ~) a *portable, altitude dial* in which hour lines for different dates are delineated around the surface of a cylinder, which is allowed to hang or stand vertically. A horizontal *gnomon* projects radially from the top of the cylinder, and is adjusted to the appropriate date around its periphery. Sometimes two alternative gnomons are supplied; a long one for winter and a short one for summer. The dial is held with the gnomon facing the sun so that the shadow falls vertically. Latitude specific. This was the **chilindrum** of *Chaucer's* monk. A Roman version from the 1st century AD was identified in 1984. Although the accepted modern term is a *pillar* ~, the term "cylindric dial" was used, for example in the 1786 *Chambers Cyclopaedia*. See also the *universal cylinder dial*.

declining ~: a *vertical dial* which does not face any of the *cardinal points* of the compass. The *sub-style* will be displaced from the *noon line*, although the latter will still lie vertically below the *dial centre*.



A pillar, shepherd's or cylinder dial.

tion dials, first described by *Samuel Foster* of *Gresham College* in the 17th

century, it is a horizontal dial with a moveable *style* and hour points which lie along a straight line lying E-W.

Dieppe ~: a style of portable dial made around Dieppe, France, by makers such as *Bloud*. The peak period was 1650-1750 and the dials were commonly ivory *diptychs* based on a *magnetic azimuth dial*.

diffraction ~: a dial invented in 1999 by M. Catamo & C. Lucarini. It has no *gnomon*, but the *dial plate* consists of a circular *diffraction* pattern, which forms a bright, multicoloured diametrical line pointing at the sun when viewed perpendicularly to the centre of the dial plate. Horizontal, altitude and equinoctial versions are also possible. The dial plate is usually made from a CD (compact disc), hence "CD dial".

digital ~: an ingenious 20th century dial. The 'gnomon' consists of a rectangular sandwich of shadow masks set parallel to the *polar axis*. This gnomon casts a shadow in which digits representing the time are sunlit. Patented, and requires great precision in manufacture.

dipleidoscope: see under *dipleidoscope* in the alphabetical listing.

diptych ~: {tablet ~} (pron. dip-tich or dip-tic) a portable (pocket) dial in which a *vertical* and a *horizontal* dial are hinged together, and a common cord *gnomon* running between them also ensures that they open to a right angle. Latitude specific. This term is, confusingly, sometimes also used to describe a monumental *open book* dial.

direct ~: a *vertical dial* which directly faces one of the *cardinal points* of the compass e.g. direct S.

direction ~: a class of dial which depends on knowledge of the position of the *meridian*. These dials must either be fixed or provided with compass. They may be contrasted to *altitude dials*.

double horizontal ~: a horizontal dial with a combined polar pointing *gnomon* and a vertical one showing the time/date on a *stereographic* projection

deviating ~: a term used by some authors (e.g. *Gibbs*) for *declining dial*.

diametral ~: one of the *equatorial projec-*

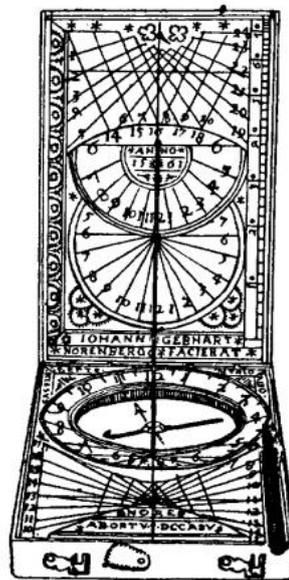
of the sky onto the horizontal plate. Capable of self orientating, although normally fixed in position, they can show many astronomical parameters. Usually attributed to *William Oughtred* in the early 17th century, early hand-engraved versions are very fine.

Egyptian ~: a range of sundials from ancient Egypt (portable and fixed) exists, the earliest being from the time of Tuthmosis III (1479-1425 BC). The portable devices appear as a long, thin 3-D letter 'L', laid with the long shaft horizontal along the sun's *azimuth*, with the upturned foot casting a shadow onto the shaft. It is very similar to the *merkhet* but has a dedicated hour scale.

elliptical ~: a term occasionally used to describe an *analemmatic dial*.

equant ~: (pron. ek-want) a modified *horizontal* ~ in which the *hour-lines* are replaced by *hour points*. These points are arranged

An ivory diptych dial with a string gnomon.



round a geometric curve chosen so that the points are equally spaced, allowing the use of a *vernier* scale and more accurate interpolation of times. Invented by *F. Sawyer* in 1972. Not related to *Ptolemy's equant point*.

equation ~: a dial showing the values of the *EoT*, usually in tabular or arc form. The term was mainly used in the first quarter of the 18th century, when the *EoT* was still a novelty.

equatorial ~: a dial in which the *dial plate* is set parallel to the *equatorial plane* and the polar-pointing *gnomon* is perpendicular to it. The dial has *hour lines* equally spaced at 15° intervals around the gnomon, and hence the dial plate may be rotated to account for *EoT*, *longitude* and *BST/DST* corrections. Sunlight falls on the underside of the dial plate from the *autumnal equinox* until the vernal equinox. For this period, the gnomon must project below the dial plate, which is delineated on both sides. An alternative form replaces the dial plate by a narrow hour ring (or half-ring) allowing the scale, inscribed on its inner circumference, to be read throughout the year. With this form, special analemma-shaped gnomons can be used to show *mean time*. Note: some authorities insist that this dial should be called an *equinoctial* ~.

equiangular ~: a term used for dial types where the *hour points* are placed at equal angles (15°) around a circle (or part of). If the *dial plane* is not parallel to

the *equatorial plane*, the mounting of the gnomon, (which does not need to be polar) must be movable to accommodate this.

equatorial projection ~: a class of dials obtained by projecting a *universal equatorial ring dial* onto any plane. Members of the class include *analemmatic*, *diametral*, *Foster Lambert* and *Parent* dials.

equinoctial ~: (pron. ec-we-noc-te-al) another (historical) name for an *equatorial* ~, preferred by some authors. It is still the term commonly used in descriptions of types of portable dials, for example the *universal equinoctial ring dial*. A stylised version of the hour ring and *gnomon* of a table-top equinoctial dial forms the BSS logo.

facet-head ~: one of the *Scottish dial* types. Fabricated in stone, it can have many complicated prism or polyhedral shapes, with each of the many faces carrying a dial or heraldic device. Particularly fine examples are at Holyroodhouse, and at Glamis Castle.

fibre optic ~: a form of *remote reading* ~ where a set of fibre optic light-guides convey sunlight from a sun-sensing face to a remote display, often inside a building.

finger ring ~: a name for a small size *ring* ~, and the most common form of *poke* ~.

flag ~: an *altitude* ~, formed by ‘unwrapping’ the scale of a *shepherd’s* ~ into a flat plane which can be shaped like a flag or pennant and is positioned perpendicular to the sun.

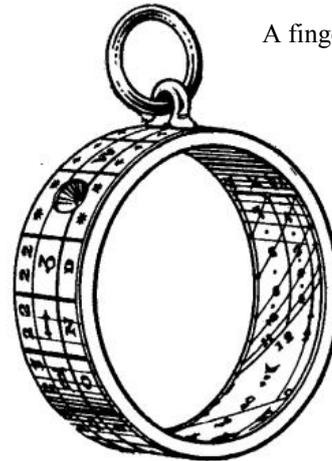
Foster-Lambert ~: a form of *equatorial projection dial*, with the projection arranged to produce a circular ring of equiangular *hour points*. It requires a gnomon movable in the N-S plane. A good example is the large reclining dial (now back at Hertmonceux Castle after a period at Cambridge) designed in 1975 by Gordon Taylor for the Royal Greenwich Observatory.

Geminus ~: a term sometimes used for a *Rojas dial*.

geographical ~: a dial in which the dial plate shows a map of the world, with curved hour lines allowing the time at any location to be indicated. The term is also used to describe dials (usually high quality horizontals) which show the times of noon at various locations around the globe.

globe ~: {**spherical** ~} a class of dial in which the ‘dial plate’ is a *globe* or sphere, usually set with its axis parallel to the Earth’s polar *axis* and often with the observer’s position at the top. The gnomon is in the form of a thin semi-circular vane which can swivel around the globe about its axis. In use, the vane is rotated until the shadow is minimised and the time read from an equiangular scale around the *equator*. It indicates the *meridian of longitude* where it is currently *noon*. An alternative type of globe dial (a *terrella*) simply uses the globe itself to form the shadow, and the time is indicated by the *terminator*. Transparent globe ~ are also possible (e.g. the Wenger ~) where the shadow of a movable point on the surface is made to fall on the centre of the globe.

Graeco-Roman ~: a general class of dial from about



A finger ring or poke dial.

the 3rd century BC (Greek) to the 4th century AD (Roman). Made of stone, they include the *hemispherium*, the *hemicyclium*, and some conical and planar dials. See Gibbs (*Sources*).

great decliner:

usually indicates a *declining dial* which nearly, but not quite, faces E or W. The *centre* of the dial falls off the *dial plate* and, as a consequence, it does not show a noon line.

hâfir ~: an Islamic dial with *unequal* hours, vertical *gnomon* and equiangular date scale of 12 segments.

halazûn ~: an Islamic dial with *unequal* hours, vertical *gnomon* and a date scale of 6 segments (each representing two signs of the zodiac).

hat ~: an *altitude dial* comprising a circular disk mounted concentrically on top of a vertical cylinder (in the form of an upside-down top hat). The dial is read by the maximum vertical length of the disk’s shadow on the outside of the cylinder.

hectemoros ~: one of the *Ptolemaic co-ordinate dials*, invented by *F. Sawyer* in 1997. It takes the form of a card or protractor which allows the *hectemoros angle* of the sun to be measured, and which also carries a *nomograph* to allow conversion to the *hour angle*.

heliochronometer: a *precision* sundial which incorporates some means to allow it to read *civil* (or *mean*) time. This is usually achieved by incorporating an *EoT* cam (as in the *Pilkington & Gibbs* heliochronometers), or by projecting a spot of light onto an *analemma*. Note: some authors use this term to describe any precision sundial.

hemispherium: {hemisphaerium} an ancient dial with the dial surface formed by a hemisphere hollowed into a horizontal (or occasionally vertical) stone face. The *gnomon* is a vertical spike (length equal to the radius of the sphere) set in the bottom of the hemisphere. It is essentially a horizontal *altitude dial*, with a shaped dial plate which prevents *sunrise and sunset* being at infinite distances. *Vitruvius* attributes the dial to *Aristarchus*.

hemicyclium: similar to the *hemispherium*, but with the south-facing part of the hemisphere cut away according to the latitude, and with the *gnomon* now projecting horizontally from the N edge. Said by *Vitruvius* to have been invented by *Berosus Chaldaeus* around 270 BC.

hidokei ~: a traditional Japanese *altitude dial*, often printed in the margins of maps. It is held horizontally and the time is indicated by the shadow of a tab folded vertically. Sometimes called a 'Basho hidokei' after a famous 17th century Japanese poet.

horizontal ~: the common or garden sundial with a horizontal *dial plate* and polar-pointing *gnomon*. Latitude specific.

inclining ~: usually applied to *portable dials* in which a *horizontal dial*, designed for a high *latitude*, typically 60°, may be inclined by raising its southern edge (in the N hemisphere) so that it may be used at locations with lower latitudes. The opposite arrangement is also occasionally found. The term is also sometimes confusingly used for near-vertical dials where the top leans away from the observer.

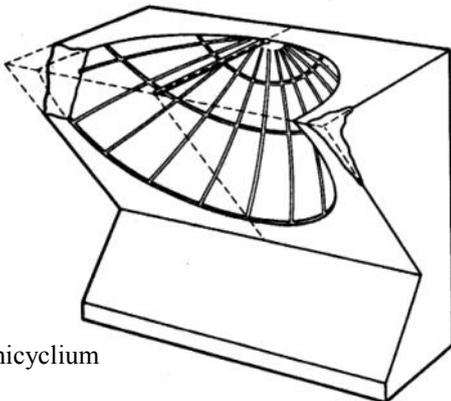
Islamic ~: a ~ with *unequal hours* and showing the Islamic prayer times.

Lambert ~: see *Foster-Lambert* ~.

lectern ~: one of the *Scottish dial* types. Fabricated in stone, they are characterised by a sloping top like a reading desk, in the *equatorial plane*, with various dials on the top and sides of the block. The top may stand on a pillar (often octagonal) carrying up to 50 different dials. A fine example is at Ladyland House.

Little Ship of Venice: see *Navicula de Venetiis*.

magnetic ~: {or **magnetic compass** ~} a small *portable* ~ in which a complete *horizontal* ~ is mounted on a compass card, and hence is self-orienting. In principle, the *magnetic variation* of the place and date where it will be used can be accommodated by rotating the dial from the magnetic N-S line of the compass. Beware: this



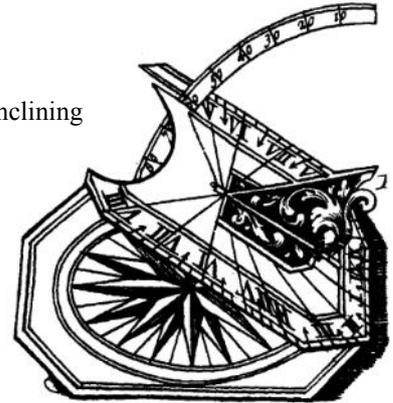
A hemicyclium

type of dial is sometimes described as just a *compass dial*.

magnetic azimuth ~: a *portable* ~, usually in *dip-tych* form. They are based on the *analemmatic dial*, with no *string gnomon* but instead the shadow of the lid is lined up to fall exactly on the base, the time being read from the compass needle on the elliptical *chapter ring*. The chapter ring position is moved in a N-S direction from a calendar *volvelle* on the underside. The dial is only accurate when the *magnetic variation* is zero.

mass ~: {or **mass clock**. Also known as a **scratch** ~} a rather basic dial from the medieval period scratched or engraved into the south-facing stonework of a church or similar

A portable inclining dial



building, often near the main door or the priest's door. Although later than Anglo-Saxon

dials, they are generally less well executed. Usually circular or semicircular in form, with a hole in the centre to accommodate a horizontal *gnomon* rod (invariably missing). Delineated, probably empirically, to show some form of *unequal hours*, there is a huge variety of design types. Some are event markers rather than true sundials.

mechanical universal equinoctial ~: {sometimes **minute** ~} a ~ that uses gearing to show accurate time on a clock face, i.e. a *solar clock*.

mirror ~: a ~ having no gnomon, but using a small, appropriately angled mirror to reflect a small spot of sunlight onto the dial face. The dial may be on a vertical wall facing N or within a building. See also *ceiling dial* or *reflecting dial* (separate definitions).

monofilar ~: a ~ in which time is marked by the point where the shadow of a thread (or other thin *gnomon*), held above the dial face, intersects a set of date lines.

moon ~: a sundial calibrated in some way so that it can tell the time by *moonlight*. No change to the basic dial is required, but a correction factor for the time is required which accounts for the *age* or *phase of the moon*. Never very accurate because of the complex nature of the moon's orbit, they generally require a nearly full moon to be able to be read clearly. Purpose-built moon dials may have either spiral hour lines or a table of moon phases (as in the famous Queens' College, Cambridge, dial). Alternatively, some dials have a concentric rotatable chapter ring.

multiple ~: simply more than one dial physically incorporated into the same dial structure.

multiple gnomon ~: a ~ in which there is a separate shadow casting element (gnomon) for each *hour line*. The elements can be points, lines or planes.

navicula de Venetiis: {or **Navicula** or **ship**~} a 16th century portable dial in the shape of a Venetian ship with a central mast. The mast pivots near its base according to the season. Based on the *Regiomontanus dial*, the few (about five) early examples are valuable.

nocturnal: see under *nocturnal* in the alphabetical listing.

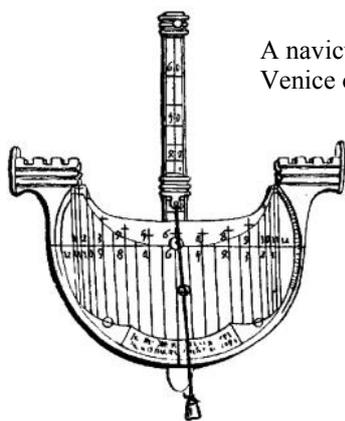
noon (or meridian) dial or **noon line**: a dial which has only one *hour line*, for *noon*. It has a *nodus* rather than a full *gnomon*. This may be in the form of a small ball on the end of a shaft or, more usually, an aperture in a plate or window opening into a building (an *oculus*). Very long, accurately-levelled meridian lines or ‘meridiana’ (running N-S) built into cathedrals were intended for the accurate determination of the *equinoxes*, *solstices* and other solar parameters. A **noon dial** (as opposed to noon line) is usually taken to mean a complete noon *analemma*, possibly including dates.

noon gun: a small cannon mounted such that focussed sunlight from an appropriately angled lens falls on the touch-hole and fires the gun at *noon*. A novelty rather than an accurate time indicator.

noon mark: a stone, or a line marked on a stone, set to receive the noon shadow of a building or other feature. The term is, however, often used interchangeably with a *noon* ~.

Nuremberg ~: a loose collective term used for the *diptych dials* made around Nuremberg, Germany, during the 16th and 17th centuries. The majority were made of ivory, featured a compass bowl in the lower leaf and had a *string gnomon*.

obelisk ~: one of the *Scottish dial* types. Fabricated in stone, it typically consists of three parts: a square *shaft* with four or five panels on each face, a *capital* or boss which is octagonal in section (possibly with the corners cut off) and, on top, a tapering *finial*. There may be up to 70 or 80 surfaces available for dials of various



A navicula, Little ship of Venice or ship dial

types. A fine example is at Kelburn Castle.

Oughtred ~: another name for a *double horizontal dial*.

Parent ~: two forms of *analemmatic* ~, either (a)

with the *dial plane* parallel to the Earth’s axis or (b) horizontal, with a series of confocal ellipses for different latitudes. First designed by *Parent* in 1701.

pelekinon ~: a form of ~ attributed to the Greeks around 100 BC. It was a horizontal dial with a vertical gnomon. In appearance, the dial resembles a butterfly or double-headed axe, and was delineated to show *unequal hours*. *Vitruvius* calls it a **pelecinum** and attributes it to Patrocles at the end of the fourth century BC.

pharetra ~: a ~ described by *Vitruvius*, its name translating as ‘quiver’. It was probably a plane *declining dial*, so named because the hour line resembled arrows in a quiver.

pillar ~: see *cylinder* ~. Although this is the modern

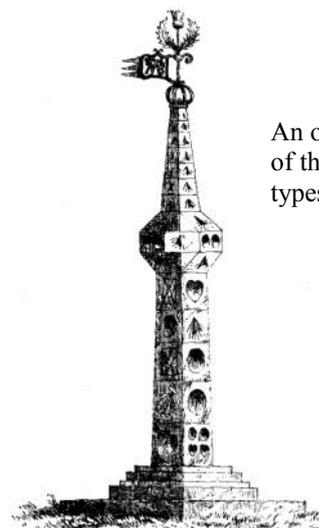
term preferred by some authorities, it is sometimes also confusingly used to describe monumental dials mounted on tall pillars.

poke ~: an old term (used for example by Shakespeare) for a pocket or *portable dial*, usually a *ring dial*.

polar ~: a ~ in which the *dial plate* is set along the E-W direction and reclines so that it is parallel to the *polar axis*. The standard polar-pointing *gnomon* is thus also parallel to the dial plate. Simple to construct, but the hour lines disappear to infinity when the sun is in the plane of the dial (although the ends of the dial plate are sometimes turned though 90° to avoid this problem). For a south-facing polar dial, the theoretical limits at the summer solstice are 6am to 6pm.

polarised light ~: a gnomon-less dial which detects the orientation of the *polarised skylight*. Its polariser/analyser system is best arranged to view a region of the sky near the N *celestial pole* (S in the southern hemisphere), allowing the *lines* to follow

al-hour low a



An obelisk dial, one of the Scottish dial types

per Alt-par-ac-the

that it does not require direct *sunlight* to work as long as there is clear sky towards the N *celestial pole*. Thought to have been invented by *Sir Charles Wheatstone* in 1848.

polyhedral ~: {**block**} a multiple dial in the form of a solid polyhedron, with a separate dial on each face. Usually each dial is some form of *decliner/recliner*, but may include *scaphe* and *polar dials* as well. Particularly common as the monumental Scottish stone lectern and obelisk dials.

portable ~: simply a dial meant to be moved from place to place, either as a pocket dial or by being transportable. In most forms, some means of orienting the dial is included, and they are often either *universal* or capable of being read at a number of fixed *latitudes*.

primary ~: any ~ on the planes of the *horizon*, the *meridian* or the *prime vertical*. Usually, this is extended to include those on the *equatorial* (equinoctial) and *polar planes*.

prism ~: a term occasionally used to describe a *multiple dial* with two or three dial faces set on the sides

standard 15° hour scale. though not particularly accurate, it has advantage

of a triangular prism.

proclining ~: a term sometimes used to describe a dial which is approximately upright but which leans forward towards the observer. A dial which leans forward by 10° will have an *inclination* of $+100^\circ$. They are sometimes also called *inclining* dials, although that term is best reserved for dials derived from a horizontal ~.

proc pan clima: a term used by *Vitruvius* to describe a *portable dial* which allows for continuous variation of *latitude*. An example is in the Museum of the History of Science, Oxford.

projection ~: a ~ drawn on a transparent plane, often a window, so that the shadows of the *hourlines* are cast on a fixed point, e.g. a mark on the floor.

Ptolemaic co-ordinate ~: a category of dials invented by *F. Sawyer* in 1997, which includes the *hectemoros* ~. The dials are in the form of a card or protractor which allow the *Ptolemaic co-ordinates* of the sun to be measured, and they also carry a *nomograph* to allow conversion to the *hour angle*.

quadrant: see under *quadrant* in the alphabetical listing.

reclining ~: strictly, an approximately *vertical dial* which leans backwards away from the observer. However, often used as a catch-all term for any non-vertical dial. The angle is defined from the horizontal towards the observer, so a dial which leans backwards by 10° from the vertical has an *inclination* $+80^\circ$.

reflecting ~: these dials have no *gnomon*, but reflect *sunlight* by means of a semi-cylindrical mirror, set with the axis of the mirror parallel to the *polar axis*. The mirror reflects the light to form a caustic curve amongst the *hour points*. For the special case of the mirror having a *cycloid* shape, the hour points are equally spaced. Note that the term reflecting dial may also be used for *ceiling dials*.

refraction ~: dials which use a clear liquid in a solid cup to compress the hour lines by *refraction*. Sometimes drawn on the inside of a drinking cup - a *chalice dial* - (see *Dial of Ahaz*) or on the bottom of a fountain basin or swimming pool. Other forms use a cylindrical lens to focus sunlight onto a curved dial plate or onto an equatorial disk (e.g. the **Benoy** dial).

Regiomontanus ~: a universal form of *card dial*, usually with the suspension point of the cord movable in two dimensions in the card plane. It is the basis for many other variants of dial and was developed by Johannes Müller (*Regiomontanus*), who first described it in his 1474 almanac.

remote reading ~: a ~ in which the sun-sensor is physically separated from the display element, with the latter often inside a building. The interconnection may be electrical or optical (see *Dial Types*, *fibre optic* ~).

ring ~: a *portable, altitude dial* in the form of a ring, with a small *aperture* in its circumference. Sometimes known as a *finger ring dial*. The ring is suspended in a vertical plane such that the aperture faces the sun. The time is then indicated on a time/

date scale on the inside of the dial. Either the suspension point or the aperture may be adjustable on the circumference to allow for *latitude* changes. Not very accurate, due to their usually small size and the fact that a very compressed date scale is needed to prevent the ring becoming too wide. These dials were known by *Vitruvius* in the first century BC. Beware: this term is also sometimes loosely used to describe a *universal equinoctial ring dial*.

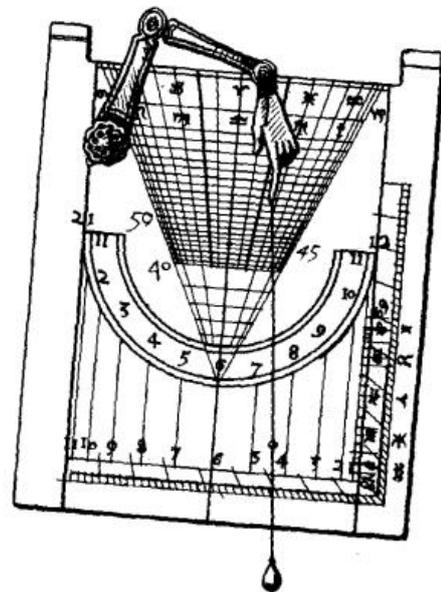
Rojas ~: a portable *altitude dial* using an *orthographic* projection, and hence similar to the *Rojas astrolabe*. Sometimes called a **Geminus** ~.

roof ~: a term used (e.g. by *Gibbs*) to describe Graeco-Roman dials in which the lines are inscribed on the surface of a part-sphere hollowed out of a block of stone. A ray of sunlight is admitted through a small hole in the top (roof) of the block. Also called a **lacunar** or a **plinthium** {*panthium*} and ascribed by *Vitruvius* to Scopinius of Syracuse. Do not confuse with the *reflected* or *ceiling* dial.

Saxon ~: see *Anglo-Saxon* ~.

scaphe ~: (pron. sk-af-ee) {*skafe*, *scaphion*} a dial in which the dial plate is a shallow dish in any plane (usually a horizontal or vertical one). The name comes from the Greek word for boat, and the dial itself is thought to have developed from the *hemispherium*. It may have a separate *gnomon* or make use of one of the edges of the dish.

Schmoyer ~: an *analemmic* ~ produced commercially by R L Schmoyer (USA) in the late 20th century.



A Regiomontanus dial, an example of a card dial

Called a 'Sunquest' dial by its maker. It featured a slotted gnomon which could be rotated to produce both halves of the *analemma*.

scientific ~: a term usually taken to mean a dial which is designed to show *equal hours*, or at least in which the effect of latitude been mathematically accounted for. Thus any dial with a polar-pointing *gnomon* is scientific, but, for example a *mass dial* is not. Most-

ly, they date from the 16th century onwards.

sciothericum telescopicum: a dial invented by *William Molyneux* in 1686. It comprised a horizontal dial with a refracting telescope mounted on the gnomon to view the sun (highly dangerous) or, more feasibly, the stars. A prototype was made by Richard Whitehead and the dialplate for another, made by John England, is at Trinity College, Cambridge.

Scottish ~: a broad category of complicated multifaceted dials produced in Scotland, mainly in the 17th and early 18th centuries. It includes *lectern*, *obelisk* and *facet-head* dials.

scratch ~: see *mass dials*.

secondary ~: any ~ not classified as a *primary* one, but most usually taken to refer to *declining* and *reclining* etc. dials.

self-orienting ~: any dial which, when correctly adjusted for the latitude and/or date, can be used to find the direction of south. Sometimes also called '**self-southing**', they usually incorporate two dials measuring different aspects of the sun's position.

shadow plane ~: a class of dial in which the *gnomon* is movable and is set by the observer so that it, and its shadow, lie in the sun's *hour plane*. The gnomon may be a plane, line or point. The *dial plate* can, if required, be any surface. A *globe dial* with a movable vane is an example of a shadow plane ~.

shepherd's ~: see *cylinder dial* for the usual meaning. A second type of shepherd's dial is a set of marks cut in the turf, so that the shepherd's crook could be used as a vertical gnomon – see Shakespeare's *Henry VI* part 3, act 2, scene 5.

ship ~: see *navicula de Ventetiis*.

sidereal ~: (pron. sy-deer-e-al) a ~ designed to show *sidereal time* by means of introducing a variable offset to the time shown by the solar shadow on an *equiangular dial*. The dials are rare, with no known public dial in the UK.

solar clock (or solar chronometer): an instrument in which a sighting of the sun, through a movable telescope or open sights, is made to display the time on a clock face by a set of gears. A famous example by *Sir Charles Wheatstone* is in the Science Museum. Note: this term is often used as a synonym for *heliometer*, but is best reserved for the definition given here.

spherical ~: see *globe dial*.

spoon ~: a rare form of *scaphe* ~ delineated in the bowl of a spoon.

spot ~: an old (probably 17th century) term for a *ceiling dial*.

stained glass ~: a (generally vertical) dial in which the *dial face* is of stained glass, and is viewed from the back, i.e. through the glass from inside the building. The gnomon remains on the outside of the building, and frequently causes cracking of the glass if supported directly from it. Typically, they were incorporated into church windows in the 17th century, although many are now in museums and there are some notable modern examples.

standing ring ~: a form of *universal equinoctial ring dial* mounted on a stand, usually including a compass.

star ~: a monumental dial similar in concept to the *cross dial*, but using a multi-pointed star. Twelve points are common, as is the six-pointed **Star of David**.

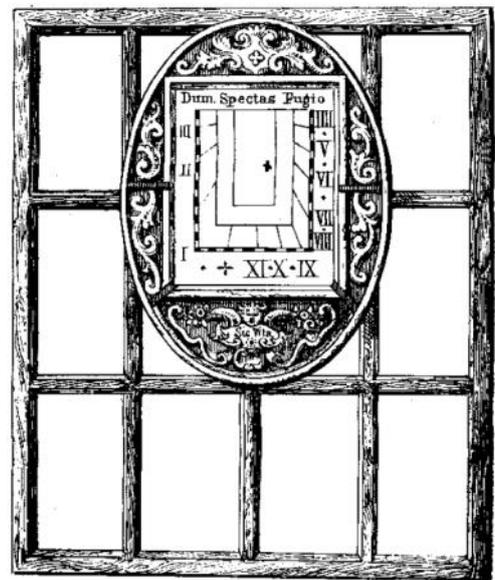
sun clock: see *solar chronometer*, dial (types of).

tablet ~: see *diptych* ~.

tidal ~: a dial delineated to give the times of the marine tides. Based on some form of *equiangular dial* (e.g. an *equatorial dial*). It bears the compass points in a circle with the names of various ports written against them. The '*establishment*' of a port is given as a compass point and, together with the hour markers, indicate the interval of time between the passage of the moon over the meridian of the port and its high tide. Not to be confused with dials showing the Anglo-Saxon *tides*.

traveller's ~: {traveller's staff} an *altitude* ~ in the form of walking stick with rings or other markers dividing its length into (usually) a hundred parts. This scale was used to measure the shadow length when the staff was held vertically. A printed scale for the appropriate *date* and *latitude* was also required.

universal ~: any *portable dial* with a means of allowing it to work at, or be adjusted for, any *latitude*. Note: sometimes the range of usage is limited to one *hemisphere*. The term is also sometimes applied, with qualifications, to dials which operate over a more limited range of latitudes, e.g. dials with, say, 30°-60°N scales.



A stained glass dial, viewed from inside the building

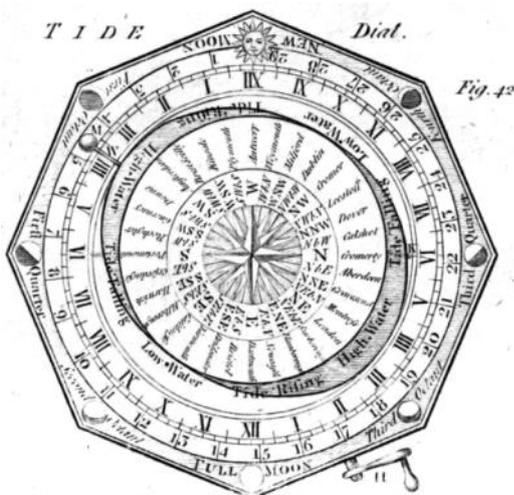
universal equinoctial ring ~: {or - equatorial - } a portable dial which looks similar to a folding version of an *armillary dial*, but with a movable suspension point to provide latitude adjustment. An *aperture* gnomon mounted on the central axis is used, the position of the aperture being adjusted to suit the *sun's declination*. The dial is self-orienting.

Large well-made versions are accurate and valuable.

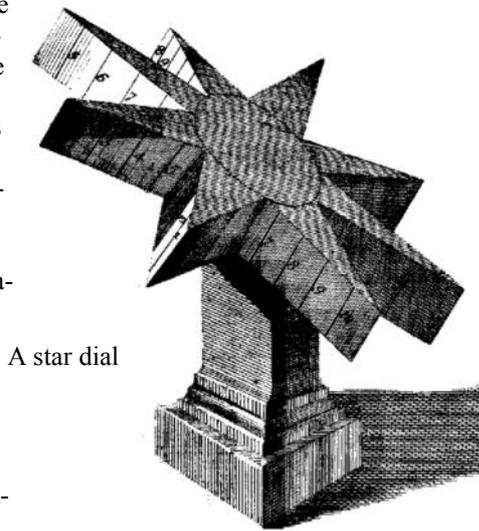
The most popular design

is usually attributed to *Oughtred*, in 1639 (published 1652) although the similar *astronomical ring* had been developed earlier.

vertical ~: any dial in which the *dial plate* is vertical.
Whitehall ~: a very famous pyramidal dial set up in the King's Privy Garden in Whitehall in 1624. It was made by the sculptor Nicholas Stone and described in detail by *Gunter*. It was destroyed in the 18th century.



A tidal dial, as illustrated in the 1796 Chambers Cyclopaedia



A star dial

window ~: {projection dial} a ~ in which the *hour lines* are marked on a window in such a way that their shadows fall across a single reading point inside the room. The lines, as drawn on the window, form an inverted, mirror-imaged *vertical dial*. This form is related to *stained glass* and *mirror (or ceiling)* ~.

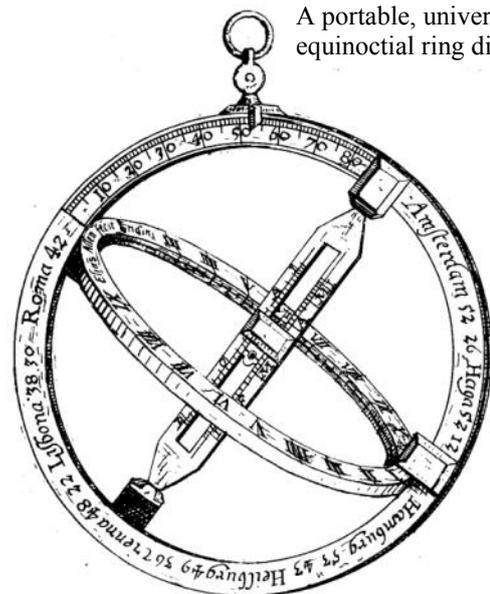
- End of Dial types -

dial plane: the *plane* in which the dial plate, and the hour indicators, lie.

dial plate: the physical structure of the dial (typically a stone or metal slab) on which the hour indicators, *furniture* etc. lie.

dialling globe: an instrument, usually of brass or wood, with a plane fitted to the horizon, and an index. Used mainly in the 18th century as an aid to drawing dials on all planes, and as a demonstration tool.

dialling scales: ruler-like (or rule-like) scales designed to help in the geometrical layout of dials. Their non-linear scales are effectively analogue computers for solving dialling equations. Standard scales, following *George Serle's* original version of 1657, and them-



A portable, universal equinoctial ring dial

selves developed from *Samuel Foster's* 1638 work, have separate scales for hours, latitude (prime) and latitude (meridian).

dialling sphere: an instrument, usually of brass, with several semicircles sliding over one another, on a moving horizon. Used mainly in the 18th century to demonstrate *spherical trigonometry*.

diallist: {dialist} see *dial*.

dial plate: {dialplate, dial face} the physical plate which carries the *hour lines* and (usually) supports the *gnomon*.

diffraction (of light): the process whereby a *ray* of light passing through a slit or past a sharp edge will spread slightly and interact with other diffracted rays. It is a consequence of the wave nature of light and hence it is strongly dependent on wavelength (colour). The scale of the effect is far too small to be observed in normal sundials (but see the *diffraction dial*).

diffraction grating: a plate with a set of closely spaced slits (usually parallel and equi-distant) which disperses incoming light into its constituent wavelengths (i.e. colours). The surface of a CD acts as a circular reflection diffraction grating.

diffuse reflection: the process whereby a ray of light is reflected from a surface equally in all directions, i.e. it appears equally bright from all observation angles. Contrast with *specular reflection*. A sheet of white paper produces (approximately) diffuse reflection.

dioptré: {dioptra} a form of *alidade*, used as the index of a *volvelle* (and also sometimes of a *quadrant* or an *astrolabe*), rotating against an angle scale.

dip (of the horizon): the angle of the observed *horizon* (due to the curve of the Earth's surface and the height of the observer, but neglecting *refraction*) below the true or astronomical horizon. It is given by:

$$\text{dip (arc-minutes)} = 1.811 \times \sqrt{\text{height (metres)}}$$

dip (magnetic): the angle that the Earth's magnetic field makes with the horizontal. It varies with geographical location and (slowly) with the date. See *Appendix IX* for values. It is measured with a dip circle or an *inclinator*.

dipleidoscope: (pron. dip-li-doh-skop) from the Greek words for “double image viewer”. Devised by James Bloxham and patented by Edward Dent in 1843. It is an instrument for observing and timing the *transit* of the sun to an accuracy of a few seconds. Essentially, it comprises a hollow equilateral prism, with the front, semi-reflecting face facing due south and approximately parallel to the polar axis. At noon, the reflection of the sun from this surface exactly coincides with a second image doubly reflected from the other two faces. Later instruments had a settable hour arc and could indicate times other than noon, requiring the front face of the prism to be strictly parallel to the Earth's axis.

diptych: literally, two leaves or pages. See *dial types*, *diptych*.

diurnal: daily, or occupying one day. Can also mean ‘of the daytime’ (as opposed to nocturnal: of the nighttime).

diurnal arches: an old term (probably 17th century) for lines on a dial face showing the length of the day time. They are thus *declination lines*, but for declinations selected to give particular lengths of the day.

domifying circles: (from the Latin *Domus Coelestris* - celestial house.) Circles on the *celestial sphere* which show the hourly position of the sun in the six *Regiomontanus (astrological) houses* that are above the horizon. On a *vertical* south dial, they are represented by straight lines emanating from the intersection of the *noon line* and the horizon line (i.e. the horizontal line on the *dial plate* perpendicular to the *nodus*). The domifying lines are angled similarly to the *hour lines*, but are numbered in the reverse direction as DOM VII (horizontal, E), DOM VIII, DOM IX, DOM X (along the noon line), DOM XI, DOM XII and DOM I (horizontal, W). On a *horizontal dial*, these lines all lie parallel to the *noon line*. See *Appendix V*.

Dominical cycle: a letter-cycle originating in the Roman period, when each day of the year was allocated the letters A,B,C,D,E,F and G in a repeating sequence. In

a given year, every weekday (e.g. Monday) has the same letter, and the cycle repeats with the 28-year Julian *leap year* cycle. The **Dominical letter** (for Sundays) is often found on *portable dials*, and is used with the *Golden Number* or the *epact* to find *Easter*. A *leap year* has two Dominical letters, one before the leap day and one after. It is sometimes called the **day letter**.

dupla: an old term for the sun's *altitude* when the shadow length is twice the height of a vertical gnomon. See *Appendix XXV*.

dusk: the evening *twilight* period.

E

earthshine: the illumination resulting from sunlight reflected from the Earth, particularly when providing low-level illumination of the ‘dark’ portion of the moon.

East: the point on the horizon 90° (measured clockwise) from the North. The sun appears to rise from the East point on the *equinoxes*.

Easter: the requirement to set the date of this Christian festival drove much of the early astronomy and calendar reforms. The standard astronomical algorithm for the date is now ‘the first Sunday after the full moon (*paschal moon*) that occurs upon, or next after, the *vernal equinox*’. However, because the rules were set by the Christian clergy before the dates of the equinoxes could be defined accurately, the vernal equinox for this calculation is always taken as 21 March. See Meeus or Duncan (in *Sources*) for a full algorithm. The extreme dates of Easter are 22 March and 25 April.

eccentricity (of the Earth's orbit): [e_c , EC] a measure of the relative sizes of the major and minor axes of the Earth's elliptical *orbit*. $e_c = 0.01671\dots$ in the year 2000 and is slowly decreasing. $e_c = 0$ would imply a circular orbit. The earliest accurate value was found by *John Flamsteed*, the first Astronomer Royal, in about 1700 (most of his results were only published after his death in 1707).

eclipse: (of the moon or the sun) the phenomenon which occurs when the Earth (or at least the observer's location), sun and moon lie on a straight line. If the moon lies in the *ecliptic plane* between the sun and the Earth, a solar eclipse occurs (either full, partial or annular, depending on the relative distances). If the Earth lies between the sun and the moon (i.e. at a full moon) a lunar eclipse is seen.

ecliptic (plane): (pron. e-clip-tic) the plane that the Earth's *orbit* traces during a year. The orbits of the moon and the planets are also close to this plane. It is the plane in which *eclipses* occur since, by definition, the sun is always on the ecliptic. It is a *great circle* on the *celestial sphere*.

ecliptic latitude: {celestial latitude} [β , ELAT] is the position of a body on the *celestial sphere*, measured along the *great circle* from the *ecliptic*. Positive to the north, negative to the south, range -90° to $+90^\circ$. It is part of the *ecliptic co-ordinate system*.

ecliptic longitude: {celestial longitude} [λ , λ_{es} , ELON] is the position of a body on the *celestial sphere* measured around the ecliptic from the *vernal equinox* positive

towards the east. It has a value of 0° to 360° and is part of the *ecliptic co-ordinate system*.

EK: see *Etos Kyriakos*.

elevation: see *altitude*.

ellipse: a *conic section* and the path the Earth follows during a year (neglecting only the small perturbations caused by the moon and the other planets). It is defined by two foci, and by a major and a minor axis. A circle is a special case of an ellipse with the two foci coincident, and the major and minor axes equalling the diameter. The elongation of an ellipse is characterised by its *eccentricity*. Also, the outline shape of an *analemmatic dial*.

ellipsoid: a closed geometric surface obtained by rotating an *ellipse* around its major or minor axis.

elongation (of the moon): the angle of the moon relative to the sun, as viewed from an observer on the Earth. The term may also be applied to the planets. An elongation of 180° implies a full moon.

embolistic: a lunar year in which there are thirteen, rather than the normal twelve, new moons.

epact (number): the age of the moon on Jan 1 diminished by one day: except in special circumstances it is the same as the age on Dec 31 of the previous year. The epacts recur in the 19-year *Metonic cycle* with infrequent changes to keep step with the real moon. Epact tables are found on old dials, particularly *portable* ones, in conjunction with lunar *volvelles* and *calendars*. In conjunction with an *almanac*, they can be used to predict the date of *Easter*. Epact was introduced as part of the *Gregorian calendar* reform as a replacement for the inaccurate *golden number* system.

epagomenal days: the five ‘days outside the months’ in the Ancient Egyptian calendar, added to the 12 months of 30 days.

ephemeris: (pron. ef-em-er-is) a table of predicted positions of celestial objects as a function of time. Astronomical *almanacs* invariably include an ephemeris for the sun.

ephemeris second: an obsolete definition of the second used between 1955 and 1965, based on the Earth’s speed of rotation. Now replaced – see *second (of time)*.

epicycle: a small circle whose centre moves around the circumference of a larger one. It was proposed as the shape of the orbit of some of the planets by *Ptolemy*.

epoch: a particular fixed instant used as a reference point on a time scale for astronomical calculations, e.g. noon 1 Jan 2000 (2451545.0 JD).

equalis: an old term for the sun’s *altitude* when the shadow length is equal to the height of a vertical gnomon, i.e. 45°. See *Appendix XXV*.

equant point: a point in *Ptolemy’s* model of the solar system around which the sun and the planets were supposed to rotate.

Equation of Time: [E, EoT] the time difference between *Local Apparent Time* (apparent solar time) and *mean solar time* at the same location. Its value varies between extremes of about +14 minutes in February and -16 minutes in October. It has two components arising from the elliptical *orbit* of the Earth and the tilt of the Earth’s *axis* to the *ecliptic*. The preferred usage

by diallists is:

$$\text{mean solar time} = \text{apparent solar time} + \text{EoT}$$

but this sign convention is by no means universal and the opposite sign is used in modern almanacs. Irrespective of the sign convention adopted, sundials will always appear slow compared to mean time in February, and fast in October/November.

The EoT varies continuously but is usually tabulated for midnight or *noon* each day at a particular location. Hence values for America (e.g. as printed in the *NASS Compendium*) can be a few seconds different from those in Europe. The noon EoT on a particular day varies slightly over the *leap year* cycles (4, 100, 400 years), and more significantly over millennia. See *Appendix XIII* for averaged values and *Equations* for an approximate mathematical expression.

The first published tabulation of the EoT was by *Christiaan Huygens* in 1665, but the knowledge of its existence probably goes back to *Ptolemy*. The first Astronomer Royal, *John Flamsteed* produced the first English tables in 1672.

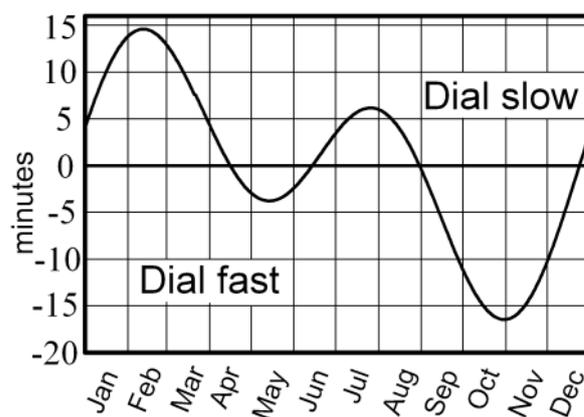
The EoT is often tabulated on dials, most frequently with circular arc labelled ‘Æquation of Natural Days’ with segments for ‘Watch faster’ and ‘Watch slower’

EoT can also be expressed as an equivalent *hour angle* [E_a, EOTA].

equator: the *great circle* of the Earth (or other celestial body) which is equidistant from the *poles*. It has, by definition, a *latitude* of 0°.

equatorial mount: a mount for an instrument (e.g. a telescope) which has one axis parallel to the polar *axis* and another at 90° to this (the *declination axis*). The *diurnal* motion of a celestial body can be followed by rotation about the polar axis alone. A polar-pointing gnomon could act as the axle for such a mount.

equatorial plane: the plane through the Earth defined by



the *equator*.

equinoctial colure: the *great circle* on the *celestial sphere* which passes through the *equinoxes* and *celestial poles*. It is one of *Sacrobosco’s* celestial circles.

equinoctial line (on a dial): is the line followed by the shadow of a *nodus* on the *equinoxes*. For a plane dial, it is a straight line perpendicular to the *sub-style*.

equinoctial plane: the plane of the *equator* extended to the *celestial sphere*, i.e. defined by the *celestial equa-*

tor.

equinoxes: (vernal or spring ~, autumnal or fall ~) literally “equal nights” i.e. equal amounts of daylight and night-time. Astronomically, the points where the plane of the *ecliptic* cuts the *celestial equator*, or the moments when the Earth is at these positions. The vernal ~, around 20-21 March, is also called the **First point of Aries** and represents the zero of *ecliptic longitude* and *right ascension*. Thus the sun has an ecliptic longitude of 0° or 180° at the ~. Day numbers of the Earth’s orbit are usually counted from this point. The autumnal equinox is around 22-23 September, and has a right ascension of 12h. The sun’s *declination* at the equinoxes is 0°.

establishment (of a port): the interval between the time of the moon passing the *meridian* and high tide at the port. It is indicated on some *equiangular dials* which can show the times of the tides (*tidal dials*). Also sometimes called the **Tidal Constant**.

Etos Kyriakos: (Greek) ‘in the year of the Lord’; the abbreviation EK has been found on dials with the date given in Greek numerals.

vection: a small irregularity in the orbit of the moon, first discovered in the 10th century by the Persian Abu’l-Wafa Al-Buzjani and, independently, by *Tycho Brahe*.

F

facsimile (of a dial): a *copy* of a dial but using different materials or a different size to the original. The ~ should be marked with its maker (and date) if it is not to be regarded as a *fake*. cf. *replica*. See *Appendix XXVIII*.

fake (sundial): a *copy* of a dial (or other artefact) made or sold with the intention to deceive the purchaser that it is original. The term derives from the Latin “fecit” (made it) often found as part of the signature on old dials. cf. *facsimile* and *replica*. See *Appendix XXVIII*.

fiducial line (or ~ edge): (pron. fid-oo-shal) the edge of an index plate or pointer against which a scale is read.

filem: an old term for a plumbline, particularly on a *card dial*, to show the vertical.

fimbriated: (adj.) having a fringe or border of finger-like projections. Used to describe the decorated vertical edge of the gnomon sometimes seen on Elizabethan dials. Also an heraldic term for a narrow border of specified tincture.

First point of Aries: see the definition for *equinoxes*. Note that, because of the *precession* of the equinoxes, this point currently lies in the constellation of Pisces.

fleur-de-lys: {fleur-de-lis} an heraldic symbol of a stylised Madonna Lily, composed of three petals bound together near their bases. Often used on dials to denote the half-hour lines.

Foster point: a theoretical point which may be used in laying-out the *hourlines* of a dial. It lies at a position on the N-S line dependent on the *latitude*. Named after *Samuel Foster* who first described it and denoted it ☐.

furniture: all features on a *dial plate* other than the *hour lines* and their numerals are referred to as dial ~. This may include *declination lines*, a *compass rose*, *EoT* graphs or tables, *mottoes* etc. Other common furniture

includes: date, maker’s and/or benefactor’s name, coats of arms, and *latitude* and (rarer) *longitude*.

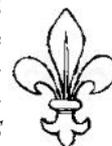
G

Geographic Position (GP): the point on the Earth’s surface directly beneath a celestial body (i.e. where a line to the body from the centre of the Earth intersects the surface).

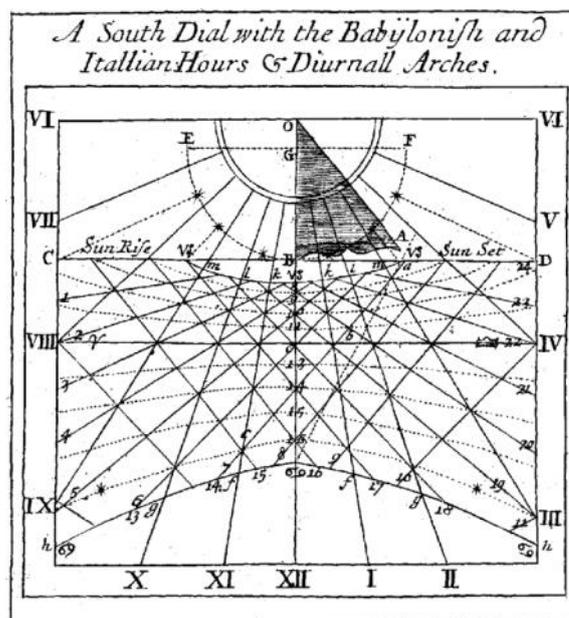
geoid: the Earth’s shape, formed by the mean sea level and its supposed extension under the land masses. It cannot sensibly be represented mathematically, and is often approximated by one of many ellipsoids. Those most likely to be encountered are the *Airy 1836* ellipsoid, used to define *Ordnance Survey* maps, and the *WGS 84* ellipsoid, used in the *GPS* system.

gibbous (moon): a description of the *moon* when the visible part is between a semicircle and the full moon. The moon phase may be described as *waxing gibbous* or *waning gibbous*. The term may also be applied to the *planets*.

globe: a spherical chart of the Earth. Note that although the Earth’s *geoid* is actually a flattened ellipsoid (i.e. slightly melon-shaped with an equatorial radius of 6378 km, and a polar radius of 6357 km) the spherical representation is used for all dialling activities with the exception, for example, of the *model GPS* system.



gnomon: (pron. no-mon) the physical structure of a sundial which casts the shadow (from the Greek for ‘indicator’). The gnomon today is most often *polar pointing* (sometimes described as an “axial gnomon”), although it may also be horizontal or vertical. The special properties of a polar pointing gnomon were known to the Moorish astronomer *Abdul Hassan Ali* in the first half of the 13th century, but its first use may be earlier. The distinction between gnomon and *style* made (and encouraged in this Glossary) in modern dialling literature is not the one used in early works, and the two words are still sometimes used in-



An old picture of a vertical dial showing a large range of furniture.

terchangeably. Originally (in English from 1546), gnomon meant a vertical pillar or rod which cast a time-indicating shadow. In 17th century dialling literature, the term "cock" was sometimes used instead of ~. Hence **gnomonics**: the science of sundialling and **gnomonist** or **gnomonicist** (seldom used): a person who practices gnomonics.

gnomon supporter: the physical structure used to support the gnomon – typically an S-shaped strut on a vertical dial or buttressing at the gnomon base of an horizontal dial.

Golden Number: a number sequence (1-19) used to describe the year number in the *metonic cycle*. It was used, together with the *Dominical letters*, to find *East-er*, and is often found on *portable dials*. In Latin, 'numerus aureus'. The number can be found by adding one to the year and then dividing by 19. The remainder is the Golden number, with a remainder of zero indicating a value of 19. Believed to have been introduced by Alexandre de Villedieu in his 1200 AD 'Massa Compote'. The system was replaced by *epact* in the *Gregorian calendar* reform.

GPS (Global Positioning System): a system of polar-orbiting satellites, run by the US Dept. of Defense, which allows hand-held radio receivers to provide accurate 3-D location information anywhere on (or near) the Earth's surface. It also provides a highly accurate clock, based on *UTC*. The system uses the WGS84 *co-ordinate system* and description of the Earth's *geoid*.

grade: (or **grada** or **gons** (obsolete)) [**grad**] a unit of angular measurement, equal to 1/100th of a right angle, or $\pi/200$ radians. Used particularly in France in the 18th and 19th centuries. Each grade may be divided into 100 centesimal minutes, each of which in turn comprises 100 centesimal seconds, eg 123^g 45^c 67^{cc}.

gradus: the Latin for *degree* (1/90th of a right angle). Its abbreviation G is often found on 16th-18th century dials. Note the possibility of confusion with the *grade*.

grazing incidence: a term used to describe illumination in which the *rays* are parallel to the receiving surface. The shadow of a point above the surface falls at infinity.

great circle: a circle on the surface of a sphere whose diameter is equal to the diameter of that sphere. Thus the circle has the same centre as the sphere. The shortest route between two points on the surface of a (solid) sphere lies on the circumference of the great circle connecting them – see *Equations, Navigation and Bearings*.

green flash: an atmospheric phenomenon occasionally observed during the final phase of *sunset*, when the upper *limb* of the sun shows as a green flash due to the complex wavelength-dependence of *atmospheric refraction*.

Greenwich Mean Time (GMT): see *GMT, time (types of)*

Greenwich Meridian: the line of *longitude* (or half a *great circle*) passing through the centre of the Airy transit circle at the Royal Observatory at Greenwich and which defines the origin of Longitude ($\lambda = 0^\circ$). It is now designated the **Prime Meridian**. Note: prior to 1884, there was no single fixed prime meridian, and

hence early sundials sometimes refer to different origins, notably Paris.

Gregorian calendar: the calendar first introduced by Pope Gregory XIII in 1582 AD and now the accepted calendar throughout the vast majority of the world. It introduced the modern system of *leap years* which results in an error of only 3 days in 10,000 years. Note that adoption of this calendar throughout Europe took an extended period (see *Appendix XXIV*). Its introduction in Britain in 1752 produced a step change of 11 days which can be seen in the difference between *EoT* tables on dials earlier than this and those on later ones. Dates after 1752 expressed in the Gregorian calendar are often denoted **New Style**.

Gresham College: a London college founded in 1597 by the merchant and financier Sir Thomas Gresham (1519-1579) in his mansion in Bishopsgate Street. It endowed professorships in seven subjects, including astronomy and geometry. *Henry Briggs* was the first incumbent of the geometry chair, and other famous professors included *Sir Christopher Wren*, Dr Robert Hooke, *Edmund Gunter* and *Samuel Foster*. The college was closely linked with the Royal Society in the 1660s.

H

halcyon days: (pron. hal-ce-on) originally, 14 days about the winter *solstice*. Now taken as simply calm, peaceful.

Hallomas: (**Halloween** in USA) All Saints' day on 1st of November. It is one of the *cross-quarter days*.

harvest moon: the full moon nearest to the autumn *equinox*. So-called because its light allowed farmers to gather in the dried harvest through the night.

hectemoria: the name used by the ancient Greeks for the *seasonal hours*.

hectemoros angle: [**hec**] (pron. hec-tem-or-os) the angle from the western horizon to the sun's position, measured around the *hectemoros* circle. Part of the *ptolemaic co-ordinate system*, and related to the *seasonal hours*.

hectemoros circle: the *great circle* that passes through the E-W points on the *horizon* and through the sun's position.

height (of a style): see *style height*.

heliacal rising: (pron. he-le-ac-l) the instant of the earliest visibility of a star in the East at dawn. The heliacal rising of the star *Sirius* was used by the ancient Egyptians to predict the coming of the annual Nile flood. Since their year had 365 days, this occurrence had a variable date.

heliocentric: an adjective to describe a model of the solar system which places a stationary sun in the centre, with the planets revolving around it.

heliochronometer: see *Dial Types (heliochronometer)*.

heliodon: a device on which a model, usually of a building, can be mounted so that a fixed light source simulates the sun's path.

heliograph: has two distinct meanings:

(a) a device for transmitting morse signals over extended distances by using an accurately aligned mirror to send flashes of sunlight to the receiving station. For long messages, the ~ has a mechanism for tracking the sun's motion.

(b) an astronomical instrument for studying sun-spots, as built by *George Airy* at Kew in 1873.

heliometer: has two distinct meanings:

(a) a telescope which produces two images of the sun which can be manipulated to determine its angular size (*semi-diameter*) accurately. Invented in 1754 by John Dollond of London, it is also used to measure angular distances between stars.

(b) a name given to the great *meridian lines* of the Italian and French cathedrals, signifying their use as research tools for solar astronomy.

heliostat: a scientific instrument which holds an image of the sun stationary, allowing extended observation (e.g. for solar spectrometry).

hemisphere (northern ~ and southern ~): one half of the Earth's globe, either north or south of the *equator*. Note that a sundial at a particular *latitude* in one hemisphere must have its hour scale mirrored for use at the reciprocal latitude in the other hemisphere.

high noon: see *noon*.

horarius angle: [*hor*] the angle from the southern horizon to the sun's position, measured around the *horarius* circle. One of the *ptolemaic co-ordinates*.

horarius circle: (pron. hor-ar-e-us) the *great circle* that passes through the N-S points on the *horizon* and through the sun's position.

horizon: the line of intersection between the sky and the Earth. For normal astronomical purposes, the observer's horizon is taken to be the *great circle* on the *celestial sphere* on which every point is 90° from the observer's *zenith*. The **observed horizon** (accounting for the curve of the earth and the height of the observer above its surface, but excluding *refraction*) is below the astronomical horizon by an angle called the *dip*. This can have a significant affect on the times of *sunrise/sunset*.

horizon obliquus: (Latin) the observer's (curved) horizon as found on an *astrolabe* plate for a particular *latitude*.

horizon rectus: (Latin) the horizon for an observer on the *equator*.

horizontal mobile: an instrument used (typically in the 17th century) for laying out sundials, particularly on *declining walls*. It consisted of a circular protractor scale on a square plate, a rotating *volvelle* with a 2×12 hour scale, and a co-centred pivoting arm used to project the *hour lines*. The device, which may also be used as a *declinatory*, was described by *Bion*.

horizontale catholicum: an *astrolabe* plate giving horizons for all possible *latitudes*.

horizontal instrument: an instrument invented by *William Oughtred* and which was a forerunner of the *double horizontal dial*. It consists of a *stereographic projection* of the sky and a horizontal gnomon which indicates the sun's *altitude*.

horologia: the collective Latin name for dials, water-clocks and sand-glasses, used in the Middle Ages.

From the earlier Greek - 'to measure hours'.

horologium: a name used to describe medieval manuscripts listing shadow lengths, deriving from the Latin name for timepieces. Modern versions have also been produced. In modern astronomy, it is also the name of a faint southern constellation ('the Clock').

hororary circles: an 18th century dialling term for the lines showing the hours on a dial. They need not be drawn circular. On a *globe*, it is the circle fixed to the N pole and fitted with an *index*.

hour: usually means 1/24th of a *mean solar day*, unless otherwise stated. Scientifically, it is defined as 3600 standard *seconds*. See *Hour (types of)* for other definitions. The word derives from the Latin 'hora', which was synonymous with prayer. In 17th century dialling literature, it is sometimes spelled "howers" or "oures"

Hours (types of):

antique ~: same as *unequal hours* or seasonal hours.

artificial ~: same as *unequal hours* or seasonal hours.

It is the term used by *Bede* as they are an artifice of the (*Saxon*) sundial.

astronomical ~: the same as *equal hours*. But see also *astronomical* in Time (types of).

Babylonian ~: number of hours elapsed since *sunrise*, with 24 equal hours per day. The origin of the term is unclear, but may be related to the fact that the ancient Babylonians originated the base-60 counting system for angles etc. They are sometimes written as 'horae ab ortu solis' or 'H. AB ORT.' on dials. See *Equations* for conversion from equal hours to Babylonian hours.

biblical ~: same as *unequal hours* or seasonal hours.

Bohemian ~: same as *Babylonian ~*.

canonical ~: the seven times of the day used to define the services or divine offices in the medieval church. These offices were based on the sixth century Rule of St. Benedict. See *Appendix IV* for details. They were still in use when the still-working clock of Salisbury Cathedral was built in 1386.

An alternative and nearly equivalent definition of canonical hours, sometimes applied to lines on early Italian dials, is the system of putting equi-angular hour lines around the base of a horizontal gnomon on a vertical south dial.

common ~: the standard 2×12 equal hour system, also called German or French ~. In Latin 'horae communes', they are often labelled 'kleine uhr' (small hours) on *Nuremberg dials*.

decimal ~: an hour system with ten equal hours per day (as sometimes used by the Chinese and ancient Egyptians, and during the French Revolution).

equal ~: any hour system where the length of an hour is independent of the date, and the same during *day-time* and *night-time*.

equatorial ~: the same as *equal hours*. Used by *Bede*.

equinoctial ~: the same as *equal hours*.

French ~: an early name for the equal hour system with 2 × 12 hours per day, beginning at midday and midnight. Sometimes written 'Oltromontane'.

French revolution ~: the equal hours according to

French Revolution time.

Great ~: a term for any of the *unequal hour* systems.

Often labelled 'grosse uhr' on *Nuremberg dials*.

Greek ~: same as *Babylonian* ~.

Italian ~: {sometimes *Italic* ~} the number of (equal) hours that have elapsed since the most recent *sunset* (hour 0), with 24 equal hours per day. They were used in many European countries during the period 1200 to 1800. They are sometimes written 'horae ab occasu solis' or 'H. AB OCC.' on dials. The two terms (Italian and *Italic*) are often used synonymously in modern works but there is evidence in older works (particularly from northern Italy) that Italian hours were counted from 30 minutes after sunset. In this case they were also called 'horae ad usum campanae' as the bells for Vespers were rung then. See *Equations* for conversion from *L.A.T.* to Italian hours.

Japanese ~: see *Appendix XX*.

modern ~: the equal hours as used in modern time systems. They may occasionally be referred to as common, European, French, German or vulgar hours.

natural ~: the same as *equal hours*.

Nuremberg ~: a hybrid *equal hour* system. The daylight hours were measured using the *Babylonian* ~ system, starting with 1 at sunrise, while the night hours started with 1 at sunset and used the *Italian* ~ system. In Latin, 'horae norimbergenses'.

octaval ~: a time system with the period of daylight divided into eight hours. Probably introduced by the Romans, circa 250AD. See *Appendix III* for the names of the daylight periods.

planetary ~: a planetary hour is the time needed for 15° of the *celestial equator* to rise above the *horizon*, counting from *sunrise*. As there is always 180° of the celestial equator above the horizon, there are 12 planetary hours from sunrise to sunset but they are unequal not only from day to day but also from hour to hour. Note: this definition is based on the writings of *Sacrobosco*, but some authors use planetary hours simply as another form of seasonal hours, with the hours associated with the 'planets'. See *Appendix VIII* for the symbols of the planets and this association. The *Zonwvlak* program uses the definition of the German scholar *Joseph Drecker* (1925) who defines a planetary hour as the time for 15° of the *ecliptic* to rise above the horizon (counting from sunrise) and are hence rather irregular.

seasonal ~: a form of *unequal hours*, usually with 12 daytime and 12 night-time hours. Named from the fact that the length of an hour varies with the *seasons*.

temporary ~: {**temporal** ~} an *unequal hour* system with 12 hours from sunrise to sunset, and 12 hours (of a different duration) from sunset to sunrise.

transalpine ~: a term used in medieval Italy ('hora oltramontana') to describe the system prevailing in northern Europe, with *equal hours* counted from *noon*.

unequal ~: an hour system where the duration of an

hour depends on the date and is different from day-time to night (except at the *equinoxes*). The number of hours during day-time is usually 12, but may be 8 and just possibly 10 (e.g. on some mass dials). Counting of the daytime hours begins at sunrise.

Welsch ~: {or **Welsh**} i.e. foreign. Same as *Italian* ~.

- **End of Hours (types of)** -

hour angle: [**h**, **HA**] the angle corresponding to the sun's position around its daily (apparent) *orbit*. Measured westward from local *noon*, it increases at a rate of 15° per hour. Thus 3pm (Local Apparent Time) is 45° and 9 am is -45°.

hour circle: a *great circle* on the *celestial sphere* that passes through the *celestial poles*. It is orthogonal to the *celestial equator*.

hour line: {**hourline**} the line on a *dial plate* indicating the shadow position at a particular time (includes fractional as well as whole hours).

hour line angle: [**X**, **HLA**] the angle that an *hour line* on a *dial plate* makes with the *noon line*. The angle increases with time (i.e. positive for the p.m. hours). Thus, for a horizontal dial in the northern hemisphere, the angle increases clockwise (hence the origin of the term) whereas for a vertical south-facing dial, it increases counter-clockwise. Beware, this convention is not used by all authors, and some define the angle with respect to the *sub-style* line.

hour point: a point on the *dial plane* indicating the crossing of the *gnomon's* shadow at a particular time. Hour points replace *hour lines* on dials where the shadow edge does not pass through the dial *centre*.

hour plane: the plane which, at any instant, contains the sun, the observer and the *N celestial pole*. The *style* and the appropriate *hour line* lie in the hour plane.

house: (astrological) a segment of the *celestial sphere*. Several methods of dividing the sphere into segments exist, the most common of which produce the signs of the *zodiac*, and the *Regiomontanus houses*.

housewife's trick (the): the method of adjusting a *horizontal dial* for the *EoT* by rotating the complete dial on its *pedestal* so that it tells the correct *clock time*, on the (erroneous) assumption that it will continue to indicate the correct time for the rest of the day. Although mathematically incorrect, it gives surprisingly reasonable results. The term was coined by A. P. Herbert (see *Sources*) in less politically correct times.

hunter's moon: the full moon following the *harvest moon*. So-called because its light allowed hunters and poachers to work through the night.

hyperbola: a *conic section*, its most common use in dialling is the shape of the *declination lines* on many types of dial.

I

Imbolic: an ancient Celtic festival held on the 2nd of February, celebrating fertility. It is one of the *cross-quarter days*.

inclination: [**i**, **I**] the angle between the back of the *dial plane* and the horizontal for *inclining* or *reclining* dials. Equivalently, it is the angle between the *zenith* and the

positive *z* *co-ordinate* of the dial. $i = 0^\circ$ implies a *horizontal* dial. For an inclining dial, $0 < i < \phi$ (the latitude of the place). For a reclining dial leaning away from the observer, $i < 90^\circ$; whilst $i > 90^\circ$ implies a proclining dial leaning forward towards the observer. Beware: this convention is not followed by all authors.

inclinometer: {**clinometer**} an instrument for measuring the *inclination* or slope of a surface. Two types are common: simple devices with a plumb-line hanging across a protractor, or precision instruments where a sensitive spirit level is moved to the horizontal position against an accurate scale. Note: the term inclinometer is also used to describe an instrument - also called a **dip circle** - for measuring the vertical component of the Earth's magnetic field.

index: besides its normal meaning of an alphabetical list, an \sim is a pointer on a scientific instrument, indicating a point on a graduated scale. The **index arm** of a sextant is the movable arm carrying the index mirror and the *fiducial line*.

inequality of the Earth's orbit: {**orbital inequality**} an old term (e.g. used by *Flamsteed*) for the *eccentricity* of the orbit.

inferior: refers to an event on the *celestial sphere* below the *horizon*. Opposite of *superior*.

inhiraf: the angle which the *qibla line* makes with the north ray of the meridian at any location.

International Date Line: the line from the N to S *poles*, approximately following the 180° line of *longitude*, through which the date alters by one day (positively if travelling from W to E). Variations from the 180° meridian are made to avoid political and geographic boundaries.

Islamic prayer lines: the lines on Islamic dials where the shadow of the *nodus* falls at the times when Muslims must pray. The times of the three most common lines are determined by a linear relationship to the *noon* shadow length of a vertical *gnomon*:

zuhr: noon shadow + $0.25 \times$ gnomon height

asr-awwal: noon shadow + gnomon height

asr-tâni: noon shadow + $2 \times$ gnomon height

isochronous: {**isochronal**} occurring in equal periods of time (e.g. the Earth's *rotation* is \sim to a good approximation).

isogonals: {**isogonic lines**} lines of equal *magnetic variation* plotted on some navigational charts.

J

Jaipur: (pron. Ji-poor) a famous early 18th century solar astronomical centre in India, constructed by the Maharaja *Jai Singh* around 1724. It includes many monumental sundials, including a famous *equatorial* one with a gnomon 27 metres high.

jifa: a measurement given on Islamic dials to indicate the quarter of the horizon of a particular place where Mecca can be found (see also *inhiraf*)

Julian calendar: the *calendar* system introduced by Emperor Julius Caesar and devised by the Greek philosopher (and court astronomer of Egypt) *Sosigenes*. Widely used from 45BC to 1582AD. By this date, it was in error (compared with the Earth's orbit) by 10 days due

to the imperfect use of *leap years* (i.e. it assumed the length of a year was 365.25 days). Dates expressed in the Julian calendar prior to 1752 in England are often denoted **Old Style**.

Julian Day: {sometimes **Julian Ephemeris Day**} [**JD**] the astronomers' scale of date and time. Used in dialling, for example, for the accurate calculation of the *EoT* and *sun's declination*. Measured continuously in decimal days since noon GMT 1 Jan, 4713BC. By tradition, since midnight is difficult to define without an accurate clock, the \sim begins at Greenwich Mean noon, that is, 12:00 UT. As an example, 9:36 GMT on 26 April 1977 is JD2,443,259.9. See *Sources* (Meeus) for a full algorithm for converting modern date/time to JD. The Julian Day count was defined by *John Herschel* in 1849, based on the 4713 BC epoch used in 1583 by *Joseph Scaliger* (France). It is commonly stated (probably erroneously) that Scaliger named the system after his father.

K

kamæl: an early Arabic navigational instrument for determining the sun's *altitude* by means of a transom and a knotted cord.

Kepler's Laws (of planetary motion): three laws which describe the motion of the planets around the sun, named after *Johannes Kepler* (1571-1630). They are:

1. Planets travel in *elliptical* (rather than circular or *epicyclic*) orbits, with the sun at one of the foci.
2. The line joining the sun and the planet sweeps out equal areas of space in equal time intervals (so that the planet moves faster when it is nearer the sun, and establishing the sun as the main controller of the planets)
3. The squares of the orbital periods are proportional to the cubes of the mean distances to the sun.

klimata: (pron. clim-arta) part of an *astrolabe*, it is a disk rotating on the *mater* with the north *celestial pole* in the centre and showing *almucantar* lines for the design location. After the ancient Greek meaning 'angle of the sun's rays', and hence the modern word 'climate'.

L

Lambert's circles: circles of construction used when drawing sets of nested *ellipses* to represent *analemmatic dials* for different *latitudes*, the dials using a common scale for the (vertical) *gnomon* position. Such sets of dials are particularly useful for a *solar compass*, e.g. the Cole sun compass used in N. Africa during the Second World War. After the mathematician *Lambert*.

Lammas: {**Lammas Day**} one of the *cross-quarter days*. It is on 1st August, and was formerly observed as the harvest festival.

latitude (geographical, of a place): [ϕ , **PHI**, **Lat**] Note: avoid LAT, since it can be confused with local apparent time. It is the angular position of a place north or south of the *equator*. Positive values in the Northern *hemisphere*, negative in the South (i.e., the South Pole has $\phi = -90^\circ$). Part of the *geographic co-ordinate sys-*

tem, the term comes from the Greek ‘latus’ (breadth).

leap second: an extra *second* inserted into *UTC* at the end of some years between 24:00:00 Dec 31 and 00:00:00 Jan 1 to ensure that *UTC* remains in step with the Earth’s *diurnal* rotation. It may also be added at the end of June. The addition is not predictable as it depends on many factors, such as the increased atmospheric drag on the Earth in El Niño years. The actual addition is performed by the Bureau International des Poids et Mesures near Paris. Leap seconds are gradually becoming more common as the rate of the Earth’s rotation slows due to energy dissipation by the tides.

leap year: years in which an extra day (February 29) is introduced so that the (*Gregorian*) calendar keeps step with the Earth’s *orbit*. The rule for leap years is that a year is a leap year if and only if the year number is divisible by 4, except years divisible by 100 which are not leap years unless they are also divisible by 400. This corresponds to the length of the year being 365.2425 *mean solar days*. This can be compared with the 365.25 days in the earlier *Julian calendar*. (The Julian leap year doubled February 24.) The leap year system causes the *EoT* (and *sun’s declination*) on a particular day of the year to exhibit a small periodic variation. Years which are not a ~ are common years.

lemniscate (curve): the term used in Latin countries for the *analemma*. From ‘lemniscus’, meaning ribbon. In English, the ~ is a mathematical curve which is similar to a spiral and is sometimes used in road design; it also looks similar to one lobe of the *analemma*.

libration (of the moon): the periodic oscillation of the moon from ‘side to side’ (and ‘up and down’) which allows an observer on the Earth to see somewhat more than half its surface.

limation: (archaic) a term used by *Flamsteed* to mean the correction of a calculation or observation, having originally (1612) had the meaning ‘filing or polishing’.

limb: part of an *astrolabe*, it is the circular ring with a scale of hours and degrees. Its first recorded English use was in 1593.

limb (of the sun or moon): the outer circumferential region of the sun (or other celestial body). The term **limb darkening** indicates that the disk of the sun does not have uniform brightness but is dimmer around the ‘edges’ due to increased optical absorption by the *photosphere*.

local apparent time: [L.A.T.] solar time. See *Time (types of)*. Hence **local apparent noon**, at the sun’s *superior transit*.

local hour angle (or just hour angle): [h, HA] *Local Apparent Time* expressed as the angular position of the sun in its daily track. Measured from *noon*, it increases by 15° per hour with increasing time (i.e., morning hours are negative). Beware, this convention is not universal.

lodestone: a naturally occurring oxide of iron, mounted with two iron poles in a non-magnetic frame. Used for magnetising compass needles, small ones were made specially for *portable dials*.

longest day: a term in common parlance, defined as the day of the year with the longest period from (astronomical) *sunrise* to sunset. It is normally used synonymously with the summer *solstice* although,

strictly, it can vary by a day depending on the exact time of the solstice and the relationship between the rate of change of the *EoT* and that of the local sunset/sunrise.

longitude (or geographic ~ to distinguish it from the ecliptic ~): [λ, λ_t, LON] the angular location of a place on the Earth’s surface measured east or west of the *Prime meridian* though Greenwich. The usual dialling convention is that longitudes W are positive, E are negative (with a range of -180° to +180°). However, note that in 1983 the International Astronomical Union perversely defined Eastward longitudes as positive, with a range 0-360°; this system is rarely found in dialling. Part of the *geographic co-ordinate system*, the term comes from the Greek ‘longus’ (length). See also *Prime Meridian*. In navigation, the preferred format is to specify three figures for the ~, e.g. 001° East.

Longitude Act: a 1715 act of the British parliament which established a Board of Longitude to manage a prize of £20,000 for a practical method of finding *longitude* at sea.

longitude correction: the correction required to *local apparent time* to translate it to the L.A.T. for the central meridian of that *time zone*. The correction is +4.0 minutes for every 1° longitude W of the time zone *meridian* (and -4.0 minutes for E). Sometimes, this correction is built into the *hour lines* by calculating the local *hour angle* for times at the zone meridian.

loxodrome: see *rhumb-line*.

luminaries: a collective term for the *sun* and the *moon*. This definition is additional to the usual one of ‘distinguished scholars’.

lunar angle: the difference between the *right ascensions* of the sun and the moon. On a standard sundial used as a *moon dial*, the L.A.T. equals the time shown by the lunar shadow plus the lunar angle expressed in hours.

lunation: the time interval between successive New Moons. The mean interval is 29 days 12 hours 44 minutes 3 seconds (the *synodic month*) but, because of the perturbing action of the sun, the difference between the shortest and longest lunations in the 20th century is about 13 hours.

lunar volvelle: a *volvelle* on a portable dial which, when set to the *age of the moon*, will allow conversion from the time indicated by *moonlight* into *solar time*.

M

Mach bands: (pron. mak) subjective light and dark bands which an observer sees when looking at a black-white edge. They are produced by the brain’s visual processing (i.e. they are not real) and have the effect of sharpening the apparent edge of a shadow. First described by the Austrian physicist *Ernst Mach* (1838-1916).

magnetic variation: {**magnetic declination, magnetic deviation**} Note, the use of the term magnetic declination is best avoided because of confusion with the other types of declination. It is the angle between the directions to the true N *pole* and the magnetic N pole. At present in the UK, the magnetic pole is very approximately 3° W of true north, and decreasing by about 12’

annually. See *Appendix IX* for more detailed and historical values. There can be large local variations to the general values, some of which can be found mapped on navigational charts. The use of a magnetic compass for aligning a permanent dial is not recommended, even if due corrections are made, as the presence of steel or magnetic rocks will cause very local variations. Originally described by *William Gilbert*.

magnitude: the brightness of a star, ranging from 1st for the brightest stars to 6th for the faintest that can be seen with the un-aided eye. Originally defined by *Ptolemy*, it is sometimes indicated on *astrolabes*.

manaeus: (pron. man-ay-us) the circle of months which formed part of the ancient *orthographic* spherical projection used by late Middle age diallists. It establishes the *sun's declination*.

maquette: a sculptor's small preliminary model. The term is used to describe small mock-ups of three-dimensional dials.

Martinmas: St. Martin's day, on 11th November. It is one of the *cross-quarter days*.

mass dial: see Dial types (*mass dial*).

mater: the heavy disk which forms the base of an *astrolabe*.

mean local time: {local mean time} see *Time (types of)*.

mean solar day: the time between successive *transits* of the fictitious mean sun (i.e. an imaginary sun which appears to circle around the *celestial equator* at a constant rate equal to the average rate of the Earth's real rotation). The basis of *civil* time keeping and the everyday meaning of 'day'.

mean time: see *Time (types of)*.

Mercator projection: a projection used to produce a 2-D map of the *globe* in which the *loxodromes* are straight lines and the map is conformal. Developed by *Gerardus Mercator* in Belgium, 1586. Modern maps have straight meridians and parallels of latitude that intersect them at right angles. The Universal Transverse Mercator (UTM) projection was developed by *Lambert* in 1772 and divides the globe into 60 UTM zones, each 6° of longitude wide.

The **Transverse Mercator** projection is obtained by projecting the sphere onto an enclosing cylinder tangential to a central meridian. This is the projection used for *Ordnance Survey* maps of the UK.

merkhēt: a *transit* instrument from ancient Egypt, consisting of a horizontal 'L' shaped stone with a plumb-bob supported from the short vertical arm. It was used in conjunction with a *bay*.

meridian: a *great circle* (or, more usually, half of a great circle) passing through the N and S *poles*. The same as a line of *longitude*. The term **local meridian** used to mean the meridian line passing through the observer's location, or its representation on the *dial face*.

meridional: south-facing (e.g. a *direct-south dial*). In more general usage, it generally means of, or from, the south.

meridian line: see *Dial Types (noon line)* for the lines inscribed in the floors of Renaissance cathedrals, etc.

metonic cycle: a cycle of 19 years (or 235 lunar months) over which the phases of the moon occur on the same

month and day. It was discovered by the Greek astronomer *Meton* c.433 BC and determines the *epact* number and the *Golden Number*. It is also the basis of the Jewish calendar. Actually, the moon runs 1½ hours slow over this period, or one day over 312.7 years. This fact has to be included in the calculations for *East-er*.

midnight: strictly, the time when the sun achieves its most negative *altitude* (or, equivalently, when its *azimuth* is ±180°). More loosely defined as half-way between *sunset* and *sunrise* or, with even less accuracy, 12 hours after local *noon*.

midsummer, midwinter (~ day): the same as summer or winter *solstice*. Note that **Midsummer** (with capital M) is a legal term for the *Quarter Day* on June 24.

mil: unit of angular measurement used in some military equipment, e.g. rangefinders, theodolites. 6400 mils = 360°. Beware of possible confusion with use as a linear measurement of 1/1000 inch used by engineers (particularly in the USA).

mileways: an obsolete term for an *hour angle* of 5°, equivalent to 20 minutes of time. So called because this is the approximate time that it takes to walk one mile.

minute (of time): now defined as 60 *seconds*. Historically, the definition was 1/60th hour, where the *hour* was derived from the rotational period of the Earth. From the medieval Latin 'pars minuta prima' (first minute, or small part).

minute of arc: see *arc minute*.

month: an interval of time loosely related to one revolution of the moon around the Earth (a 'moonth'). The calendar month derives from the **synodic month** (full-moon to full-moon) which averages 29.53059 days. The **anomalistic month** (*perigee* to *perigee*) averages 27.55 days.

moon: the natural satellite of the Earth. It has a mean distance from the Earth of 384.4×10^3 km and a semi-diameter at mean distance of 15' 33". The inclination of its orbit to the ecliptic is 5° 8' 43". Note: 'Moon' with an initial capital letter is sometimes used to refer to the Earth's moon, rather than the moons of other planets.

moondial: see *Dials (types of)*.

moonlight: rays of light which reach the observer directly from the moon, having originally been *sunlight* reflected by the moon's surface. There is usually sufficient moonlight to cast a shadow only between the 1st and 3rd quarters of the moon. Since the angular size of the moon is approximately the same as that of the sun, the ratio of *umbra* to *penumbra* of a moon shadow is also the same as that for a sun shadow.

motto: a sentence, phrase or verse inscribed on a dial expressing an appropriate sentiment. Mottoes started appearing on dials in the late 16th century but were particularly popular in the 19th century.

N

nadir: the point on the *celestial sphere* that is diametrically opposite the observer's *zenith*.

nautical mile: a distance (6080 feet or 1853 metres) de-

terminated as 1 arc-minute of *longitude* at the *equator*.

New Style: dates after 1752, expressed in the *Gregorian calendar* introduced then in England. Contrast to *Old Style*.

night: {**night-time**} the period of darkness between *sunset and sunrise*.

nocturnal: (noun) a fixed or, more usually, portable instrument used to tell time by the apparent revolution of the stars on the *celestial sphere*. The stars most often used on these instruments are either the ‘guards’ of the Little Bear (Ursa Minor) or the ‘pointers’ of the Great Bear or Plough (Ursa Major). These are known as the Little Dipper and Big Dipper, respectively, in the USA. Most nocturnals have inscriptions ‘GB’ and ‘LB’ on their scales. The term ~ can also be used as an adjective, meaning ‘of the night’.

nodus: a point which casts a shadow to indicate the time and/or date on a *dial face*. It may take the form of a small sphere or a notch on a polar-pointing *gnomon*, or it may be the tip of a gnomon with an arbitrary (usually horizontal or vertical) orientation.

nodus height: [N, NH] the height (distance) of a *nodus* perpendicular to the *dial plane*. It is also the same as a vertical style height.

nomogram: {**nomograph**} a system of graphs showing relationships between three or more variables. From the Greek ‘nomos’ (law).

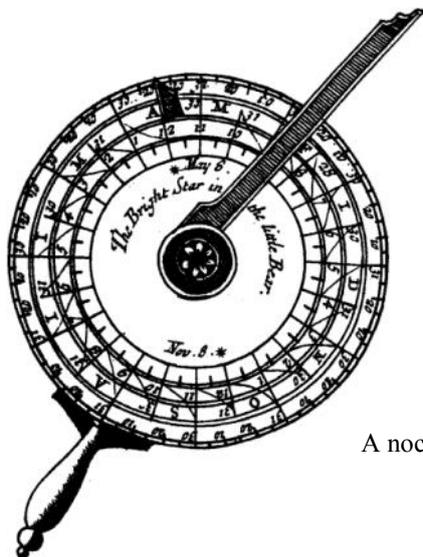
nonius: a device similar to a *vernier* for interpolating readings on an angular scale, but using a large number of concentric scales rather than a single movable one. Named after the 16th century Portuguese mathematician *Pedro Nōnes*.

noon: the time of the sun’s *transit* each day. Equivalently, the time that the sun reaches its greatest *altitude* for that day. Note that noon is specific to the observer’s location, unlike 12:00 o’clock with which it is often confused.

The word ~ originates from the Latin ‘nonus’ or ninth, indicating the ninth hour of the day counting from sunrise. By 1420 it meant the *canonical* hour or ecclesiastical office of Nones, so noon gradually became associated with the beginning of this office.

High ~ has become synonymous with noon, especially in

it in-



A nocturnal.

IV) when the sun

was at its highest.

noon cross: a cross shape often seen instead of XII on the *noon line* of dials. It can have many forms, many of which look like an Iron or Maltese cross. The nearest heraldic term is the *cross patty*.

noon deficit: the difference in the sun’s *declination* between the true *solstice* and *noon* on the day of the solstice. With a maximum period of 12 hours between these two occasions, the noon deficit is always less than 4 arc-seconds.

noon gap: {**gnomon gap** or **split noon**} the gap in the hour scale of a dial to account for the finite thickness of the *gnomon*. It is positioned on the dial plate where the sun is in the same plane as the gnomon, i.e. at *noon* for horizontal or direct S dials. A gnomon gap is occasionally seen on the *sub-style* of a *declining* dial.

noon gun: see *Dial types (noon gun)*.

noon line (on a dial): simply the *hour line* corresponding to noon, it is the most important line from which the others are usually calculated. It is the line which most often carries an *analemma*.

noon marker: a single mark or stone in the ground (or on a wall) set to show noon when crossed by the shadow of a convenient vertical edge - for example, a stick or edge of a wall. Sometimes also called a *shepherd’s dial*.

North: the intersection of the local *meridian* with the *horizon*, in the direction of the north *celestial pole*.

North Pole: the point on the Earth’s surface and its *axis* with a latitude of +90°. It lies in the direction of the **North celestial pole**, from which the Earth is seen to rotate anti-clockwise.

numerals: The numerals on dials are usually either **Modern** (the usual 0-9 used in English, and often called Arabic or Arabic-Hindu) or, especially on older dials, **Roman numerals** (I, II, .XII etc.). **Greek numerals** are also occasionally found. See *Appendices VI and XIX* for the form of these numerals and their early precursors. Note that it is common to find IIII in place of IV on some dials particularly, though not exclusively, in the 16th-18th centuries. A convention sometimes used on dials with more than one hour ring is to use Roman numerals for *Local Apparent Time*, and Modern ones for *civil time* (often *BST* etc.). Many other forms of numerals (e.g. Chinese, Turkish) are used worldwide - see *Appendix XX* for Japanese numerals.

nutation: a small periodic (principal time constant of 18 years 220 days) oscillation of the rotational *axis* of the Earth about its mean position. Discovered by *James Bradley* in 1748. The disturbance of the idealised orbit of the Earth (as a two-body system) is due to the gravitational attraction of the Earth’s equatorial bulge by the moon and, to a lesser extent, the other planets. Nutation introduces small changes, typically 7 arcseconds annually, to the *precession* of the *equinoxes*.

O

obelisk: a tall tapering shaft of stone, usually monolithic with a square or rectangular section ending with a pyramidal apex. Prominent in Ancient Egypt as a solar symbol, often at the entrance to tombs or as a cult ob-

ject in shrines to the sun.

obliquity (of the ecliptic): {sometimes the **slant**} [**ε**, **EPS**] is the angle between the Earth's *equatorial plane* and the *ecliptic*. The current mean value of the obliquity (i.e. ignoring its *nutation*) is $23^{\circ} 26' 21''$, decreasing by $23''$ over the next 50 years. Note that this figure sets the position of the *tropics*. The changes in \sim are largely caused by the perturbing force of the planets, primarily Venus and Jupiter.

obtuse angle: an angle of greater than 90° and less than 180° .

oculus: the aperture in a window or wall admitting the ray of sunlight for a *meridian line*.

o'clock: a contraction of 'of the clock', usually implying *civil time* as told by a mechanical clock. The term first occurred (c.1370) in *Chaucer's Canterbury tales*. In 17th century dialling literature, it is sometimes written 'aclock'.

occidental: west-facing (e.g. a *direct-west dial*). In more general usage, it generally means of, or from, the west. From the Latin for west, 'occidens' - literally 'setting'.

octant: a navigational instrument and forerunner of the later *sextant*. Its sector is an eighth of a full circle (hence its name) and it allows measurement of the sun's *altitude* over a full 90° .

Old Style: dates prior to 1752, expressed in the *Julian calendar* then in use in England. Contrast to *New Style*.

opposition: (astronomical) the occasion when two celestial bodies are opposite each other in the sky and their celestial longitudes differ by 180° .

orbit (of the Earth): the path of the Earth around the sun. For dialling purposes, this is taken as elliptical (or even circular), with a very small *eccentricity*, i.e., it ignores the small perturbations due to the effects of the moon and other planets.

oriental: east-facing (e.g. a *direct-east dial*). In more general usage, it generally means of, or from, the east. From the Latin for east, 'oriens' - literally, 'rising'.

origin: the (0,0) point (or (0,0,0) in three dimensions) of a co-ordinate system used to describe a *dial plane*. It is usual to place this point at the *centre* of the dial (if it exists), but it is sometimes placed at the *sub-nodus* point.

orrery: (pron. or-rer-re) (sometimes called a **planetarium**) a physical model of the solar system, used for demonstration purposes. Named after Charles Boyle, 4th Earl of Orrery, who had an early example built by *John Rowley* in 1712. Sometimes powered by clockwork to provide the correct relative orbital periods of the planets. Early examples are very valuable. See also *tellurian*.

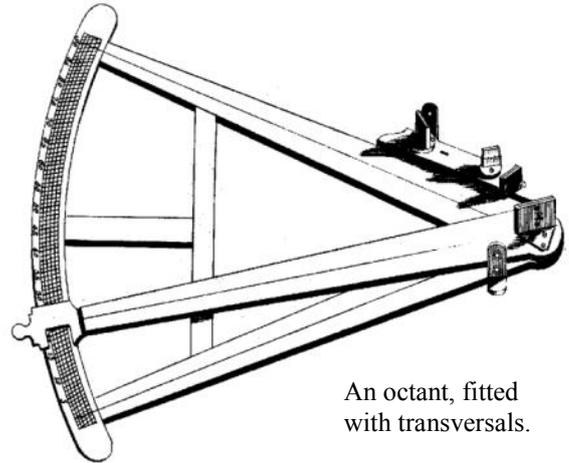
orthography: the art of drawing anything without perspective, as though viewed from infinity. In dialling, the sphere so drawn consists of circles, straight lines and *ellipses*. Hence orthographic (or orthogonal) projection, which is used in the Rojas type of universal *astrolabe*.

ortho-style: a *style* which is perpendicular to the dial plate. It was used in many ancient dials.

P

panorganan: a universal instrument described by *Wil-*

liam Leybourne in 1672. It is similar to a *Gunter's quadrant* but is for multiple latitudes and includes



An octant, fitted with transversals.

scales commonly found on *sectors*.

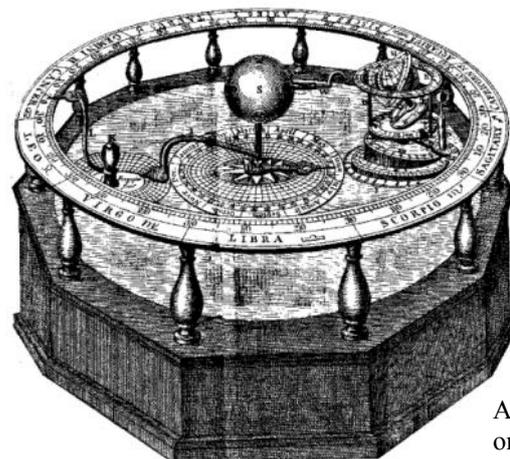
parabola: a mathematical term for the *conic section* obtained by cutting a cone with a plane parallel to its generator (or 'edge'). A **parabolic** surface, obtained by rotating a parabola about its own axis, is much used for mirrors as it has the property of focusing parallel rays of light to a point focus without spherical aberration.

parallax: the effect whereby the apparent position or direction of an object changes with the observation point. See *solar parallax* for its affect on solar parameters. The effect can affect the accuracy of reading scales.

parallactic angle: [η] the angle of the *polar triangle* between the directions to the *pole* and to the *zenith* at the celestial object. Hence it is the angle between the vertical and the *hour circle*, of use in calculating the effects of astronomical *refraction*.

parapegma: an Ancient Greek astronomical calendar invented by *Meton* and *Euctemon*. It consisted of a stone tablet with movable pegs and an inscription to indicate the correspondence between particular stars and the civil date. Later versions also showed meteorological forecasts associated with the risings of certain stars.

paschal moon: (pron. pas-kal) the full moon which falls on or next after March 21. Important for the determi-



nation of Easter. **patina:** coloured, metallic compounds

An early orrery.

(usually oxides and sulphides) which form on metal surfaces left exposed to the atmosphere. The actual colour depends principally on the metal, but also on the impurities in the atmosphere resulting from pollution or proximity to the sea. Typically, copper-containing alloys develop a greenish colour.

pedestal: the supporting structure for a dial, particularly horizontals. Usually of stone, it may comprise several different pieces and brings the dial to a convenient viewing position. See *Appendix VI* for more details of architectural terms.

pelorus: an instrument for finding the solar *azimuth*, consisting of a magnetic compass and an *alidade*, with some means (e.g. mirrors, prisms, shades) of simultaneously viewing the sun and the compass needle.

penumbra: the area of partial shadow surrounding the central *umbra*. It is due to the finite angular size of the sun. An observer standing in the penumbra would observe only part of the sun's disk.

perigee: (pron. pe-ri-gee) the point in the moon's (or other satellite's) orbit when it comes closest to the Earth.

perihelion: (pron. perry-he-le-on) the point in the Earth's *orbit* when it comes closest to the sun. It occurs during the first week of January which is why the *EoT* is changing fastest in the winter.

perpetual calendar: a device, usually in the form of a circular plate with one or two rotating engraved disks, for finding the day of the week for any date (over a wide range of years). They are often combined with *portable dials* as part of a *compendium*. More sophisticated versions have extra tables for Saint's Days and similar data.

phase (or age) of the moon: the approximately monthly cycle of the angular separation of the sun and the moon, leading to the sequence of new, waxing, full and waning moons. The **age** (as seen, for example, in tables associated with *moon dials*) is measured in days since the last new moon. Astronomically, the phase of the moon is defined as the angle between the sun and the moon measured from the Earth (the *lunar angle*). The mean length of the *synodic* (i.e., lunar) month is 29.53059 days (usually approximated to 29½ days in the lunar mechanisms of clocks).

photosphere: the outer envelope of the sun which produces the visible light by which it is seen.

pinnules: sighting pinholes (usually in pairs) in an alignment device, e.g. an *alidade*.

plane: a flat surface. More precisely, it is a surface such that every straight line joining any two points on it lies wholly in it, or such that the intersection of two such surfaces is a straight line.

planet: astronomically, a celestial body in orbit around a star. The five planets of the solar system known to the ancients were Mercury, Venus, Mars, Jupiter and Saturn. In addition, they often counted the Sun and the Moon as planets; for example, in the *planetary hours* system. See *Appendix VIII* for symbols.

planetarium: see *orrery*.

planisphere: a map of part of the *celestial sphere*, formed by a projection of the sphere onto a flat plane and showing (or adjustable for) the positions of the

stars at a particular time and location.

Platonic solids: the five regular solids (figures like the cube, regular pyramid etc. with all their faces, sides and angles equal) which *Kepler* used as spacers between the planets.

plinth: the base part of a *pedestal*, normally resting on the ground. Note that some authors use ~ to refer to the whole of the pedestal. See *Appendix VII* for more details of architectural terms.

plumb-line: a freely suspended line with a weight (or plumb-bob) at its lower end, used for defining the vertical.

plummet: the form of *plumb-line* incorporated in a portable dial and used for levelling it. It usually consists of a solid elongated cylinder suspended by a joint with free movement in the horizontal axes, above a datum point.

popble: the bead on the *plumb-line* of a *card dial*.

point (of the compass): equal to $1/32^{\text{nd}}$ of a full circle, i.e. $11\frac{1}{4}^{\circ}$. Often found on *compass roses* and labelled, for example, SWbW (i.e. south-west by west). Much used by early navigators for measuring bearings but largely superseded by the 18th century measurements using degrees.

polar axis: see *axis*.

polar co-ordinates: see *co-ordinates*.

polar distance: the distance (as an angle) of the sun from the elevated *celestial pole*; the *complement* of the *declination*.

polarised light: light in which the electromagnetic waves have a single plane of vibration in a direction perpendicular to the direction of propagation. Plane polarising filters allow the transmission of light rays with only a single selected plane of polarisation. Discovered by *Christiaan Huygens* (1635-1703) and investigated mathematically in the 1870s by Lord Rayleigh. *Sunlight* is randomly polarised, but *skylight* is partially plane polarised, with the direction of polarisation at any point in the sky being perpendicular to the plane containing the point, the sun and the observer. The proportion of the skylight which is polarised is a maximum in the *principal plane* and at 90° to the sun. The proportion is always less than 75%, and substantially less in slightly hazy conditions.

Polaris (or Pole Star): actually α Ursae Minoris, it is the star which appears quite close to the N *celestial pole* and is frequently used for finding north by navigators. It currently appears to rotate daily around a circle of radius 1° , so it requires some knowledge if it is to be used for aligning a sundial. The size of this circle varies over the centuries with the *precession* of the equinoxes.

polar plane: any plane which includes the Earth's *axis*.

polar triangle: the *spherical triangle* on the *celestial sphere* whose vertices are at the *pole*, the *zenith*, and a celestial body, with respective angles of the *hour angle*, the *azimuth*, and the *parallactic angle*. The arcs joining these are the *co-latitude*, the north polar distance ($90^{\circ}-\delta$) and the *zenith distance*. The polar triangle is fundamental to the operation of most types of sundial, whose function it is to derive the hour angle, and hence the time, given any three of the other quantities.

poles (N and S of the Earth): the locations on the Earth's sphere with *latitudes* of +90° (N) and -90° (S).

pole's elevation: a term used in early dialling literature for the *style height*. Note that although this is a logical term for a horizontal dial, it can lead to confusion on vertical dials, where the angle is measured from the dial plane, rather than the horizontal.

polos: an old term for a polar-pointing *style*.

post meridiem (p.m.): the portion of the day between *noon* and *midnight*.

precession (of the equinoxes): the slow westward progression of the *equinoxes* on the *ecliptic*. It is caused by the drift of the Earth's *axis* in space, as in a precessing spinning top. The position of the poles of the Earth's axis rotate about the ecliptic poles once in about 26,000 years. As a consequence, the vernal equinox regresses by about 50 arc-seconds per year along the ecliptic. It is caused predominantly by the gravitational force of the sun and the moon on the Earth's equatorial bulge. Secondary effects, due to the other planets, give a rotation of the ecliptic plane of 47 arc-seconds per century.

The first measurement of precession was made by *Hiparchus* in 129 BC.

precision (of a dial): a combination of the *resolution* and *accuracy* of a dial, it gives a measure of how closely (and correctly) it indicates any time.

Prime meridian: the *meridian line* defined as the origin for *longitudes*. Now synonymous with the *Greenwich meridian*, before 1884 various countries defined their own origin. The early Greeks used Rhodes or Alexandria. *Ptolemy* used the Fortunate Islands, assumed to be Ferro in the Canary Islands by scholars in the Renaissance. *Nuremberg* was common for dials made there, and in relatively modern times many maritime nations had their own locations; Paris in particular continued to be used even post-1884. Note that the 0° longitude line used by the *GPS* system is actually a mean value, periodically recalculated to allow for tectonic drift etc. and currently lies approximately 38 m east of the Greenwich line.

Prime vertical: the vertical circle perpendicular to the *meridian*. It passes through the E and W points.

Primum Mobile: (pron. pree-mum mo-be-lay) an old term for the supposed crystal sphere carrying the stars in their orbits around the earth.

principal plane: {vertical plane} the plane obtained by varying the sun's *altitude* whilst its *azimuth* is constant. Perpendicular to the *almucantar*.

prosthaphaeretical arc: a term introduced by *Samuel Foster* to describe an arc on the surface of the Earth between the location of an *inclining/declining* dial and the position where it would be identical to a horizontal dial (i.e. the *complementary dial*). In astronomy, **prosthaphaerisis** was the adding of a small amount to an observed value (obsolete).

Ptolemy's rulers (of parallax): an interconnected set of three linear scales used to measure the angular positions of stars, particularly by Regiomontanus and the Nuremberg group in the 1460s. Sometimes called (e.g. by *Flamsteed*) a **triquetrum**.

Q

Qibla line: sometimes found on Arabic dials, it is an *azimuth* line on the *dial plate* starting at the *centre* and pointing to Mecca.

quadrant: {quadrans} a term used for a large genus of astronomical and navigational instruments. In the form of a quarter-circle, it incorporates a sun or star sighting device along one of its radial edges and a plumb-bob hanging from the centre of the circle. The old **quadrans vetus** was originally an Islamic invention which provides *seasonal hours* but is only truly accurate for an observer on the equator. The **quadrans novus**, invented by Profatius in 1288, was more accurate. It incorporated the circular scale of the *astrolabe* folded into a quadrant but it was difficult to read. The 1438 **horary quadrant** of von Gmunden was one of several attempts to improve on this. The **Gunter** ~ (after *Edward Gunter*, c.1623) is latitude dependent and employs a *stereographic* projection. **Sutton's** ~ is a stereographic projection of one quarter of the celestial sphere. The **navigational** ~ is actually an octant (eighth of a circle) with two reflecting mirrors replacing the plumb-bob. See BSS Bulletin 14(i) for a fuller discussion of quadrants. For the **Davis** ~, see *backstaff*.

quadrat: another name for the *shadow square*.

quadratum nauticum: a navigational instrument, usually 16th century Flemish, for finding a course between two points of known *latitude* and *longitude* without calculation.

quadrupla: an old term for the sun's *altitude* when the shadow length is four times the height of a vertical gnomon. See *Appendix XXV*.

Quarter days: the first or last days of each quarter of the year, on which rent or interest is due. These dates are occasionally used instead of the *zodiac* signs for *declination lines* on dials. See *Appendix XII* for their names and dates.

quincunx: five dots arranged as on dice. It sometimes appears on *mass dials* at *noon* or service times.

quintupla: an old term for the sun's *altitude* when the shadow length is five times the height of a vertical gnomon. See *Appendix XXV*.

R

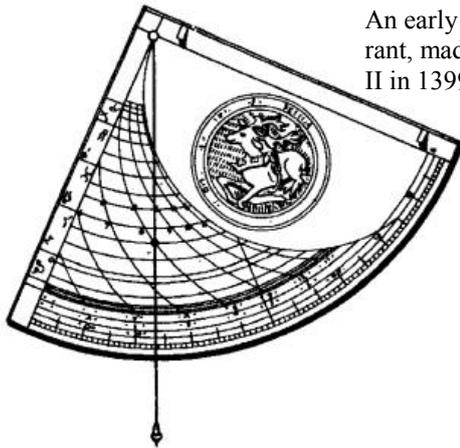
radian: [rad] the primary unit of angular measurement, it is the central angle subtended by an arc of a circle equal in length to its radius. 2π radians = 360° or 1 rad \approx 57.3°.

ray: a single line or narrow beam of light.

reclination: a term sometimes used for the angle by which a *reclining dial* leans away from the observer (i.e. the complement of the *inclination*). It is more consistent, however, to translate this into the equivalent *inclination*.

rectificatory: an old term for a right-angled triangle where the other two angles are the *latitude* and *co-latitude*. Used particularly in the graphical construction of dials.

rectify: (verb) an old term for setting up a dial ready for



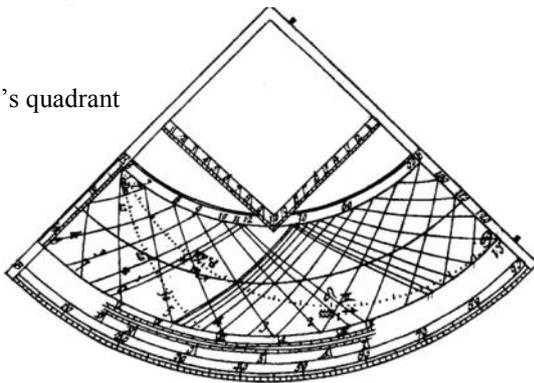
An early English quadrant, made for Richard II in 1399.

use, e.g. positioning the bead on a *Capuchin dial*.

reflection (of light): the process whereby a ray of light

is
Gunter's quadrant

re-



directed by a surface. Reflection can be either *specular* or *diffuse*, or a combination of both. It is independent of the wavelength (colour) of the light.

reflex angle: an angle of greater than 180°.

refraction: the 'bending' of light at the interface of two materials of different refractive indices. It accounts for the focusing action of lenses. In dialling, use is made of ~ in dials which use a clear liquid in a solid cup to compress the hour lines, or which use a cylindrical lens to focus *sunlight* onto a curved *dial plate*. **Atmospheric refraction** (due to the curve of the Earth's surface and the variation of atmospheric density with height, in turn dependent on meteorological conditions) is the effect which makes the sun (or other celestial body) look slightly higher in the sky than its true astronomical position. It is usually only significant when the sun is within a few degrees of the *horizon*. At 0° altitude, the bending is equivalent to approximately 34 arc-minutes, so that it is possible to see the sun when it has actually just sunk below the horizon. See *Equations*. This effect is not generally included in normal sundials but it must be allowed for when calculating solar parameters from observations using *meridian lines*.

The **refractive index** [μ , MU] of a medium (or its index of refraction), needed to calculate these effects, is defined as the ratio of the speed of light in a vacuum to its speed in the medium.

Regiomontanus houses: an astrological division of the *celestial sphere* into 12 segments or houses. The division is performed in equal segments around the *celestial equator*, rather than around the *ecliptic* as is done for the normal signs of the *zodiac*. The houses are numbered I to XII, beginning at the east point of the

horizon and are, confusingly, associated with the standard zodiac signs with I corresponding to Aries. Only the last 6 of the signs appear above the horizon. They are shown as *domifying circles* on some old dials.

replica (of a dial): an exact *copy* of an original dial, usually made by a mechanical means so that all details, imperfections etc. are copied. Typical methods are by silicone mould-making and electroforming. The ~ should be clearly marked with its maker and date if it is not to be regarded as a *fake*. cf. *facsimile*. See *Appendix XXVIII*.

resolution (of a dial): the smallest time increment to which the scale on a dial can be read. Contrast with *accuracy*. See also *precision*.

rete: {net or spider} (usually pron. ree-tee) part of an *astrolabe*, it is the fretted disc containing a number of star pointers, and which can be turned on the *mater* until the star's pointer crosses the altitude circle on the *stereographic* projection, allowing the time to be read off (assuming the date is known). The term ~ has sometimes (first reference in 1677) been used as a graduated scale fixed to an astronomical telescope.

reticule: fine lines or scales on an optical element in a sighting device (e.g. a telescope) to aid in alignment or measurement of an object.

revolve: (astronomical) to orbit around another body, e.g. the Earth revolves around the sun. Contrast to *rotate*.

rhumb: (nautical) any of the 32 points of the *compass*, or the angle between two successive compass points.

rhumb-line: a line cutting all *meridians* at the same angle, and hence the line followed by a ship sailing in a fixed direction. Sometimes called a **loxodromic** line. Occasionally seen as dial *furniture*.

right ascension: [α , RA] a co-ordinate used by astronomers, as part of the *equatorial co-ordinate system*, (together with *declination*) to define the position of a celestial body. It is the angular distance measured along the *celestial equator* (positive to the east) from the *vernal equinox* to the intersection of the celestial equator with the *hour circle* through the point in question. Usually measured from 0 to 24 hours, but sometimes 2×12 hours or 0° to 360°.

root (of a gnomon): The fixing between the *gnomon* and the *dial plate*.

rotate: (astronomical) to spin on its own axis, e.g. the Earth rotates on its polar *axis*. Contrast to *revolve*.

Rudolphine tables: tables of planetary motions, begun by *Tycho Brahe* and eventually published in 1627 by *Kepler*, using his new *laws*. Named after the Holy Roman Emperor Rudolf II who sponsored the work.

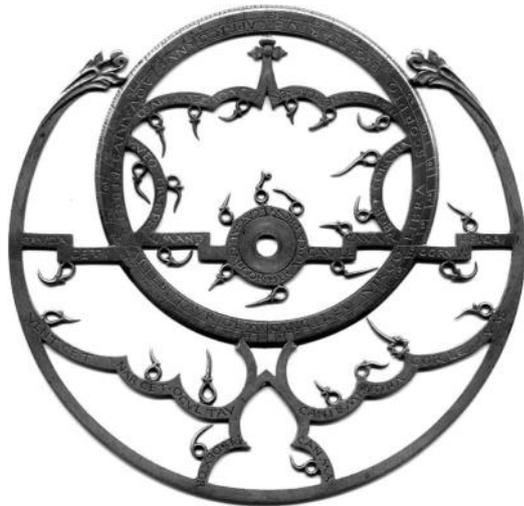
rule of three: interpolation. Sometimes found in astrological texts.

ruler: {rule} a scale marked out along a straight edge. Often non-linear for special purposes, e.g. *dialling scales*. Note that the two words are often used interchangeably, but that some authors insist on one or the other.

rundle: a term used by, for example, *Gunther* for a disk which forms part of a *volvelle*.

S

Samhain: an ancient Celtic festival held on the 1st of No-



An ornate rete with pointers for 30 stars.

vember. It is one of the *cross-quarter days*.

saros cycle: a cycle of 18 years 11 days 8 hours (6585.33 days or 223 *lunations*) between repetitions of *eclipses*.

scales: see *dialling scales*.

scattering (of light): the process whereby a *ray* of light hits a small particle and is redirected over a wide range of solid angles. The exact distribution of the scattered light is a complex function of the size of the particle relative to the wavelength, and to its absolute size. It is responsible for the production of the blue *skylight*.

sciagraphy: {*skiagraphy, sciatherics*} the art or science of shading and shadows. From *sciaterics* or *scio-terics* - the name for gnomonics in ancient Greece.

sciaterra: an instrument described by *Bion* for drawing *declination lines* on dials. It usually took the form of an addition to a *horizontal mobile*, showing shadow lengths as a function of date.

sciothericum telescopicum: see under *Dial (types of)*.

seasons: the ~ are defined astronomically as follows:

Spring: from the vernal *equinox* to the summer *solstice*

Summer: from the summer solstice to the autumnal equinox

Autumn: from the autumnal equinox to the winter solstice

Winter: from the winter solstice to the vernal equinox

Because of the shape of the Earth's *orbit*, these definitions result in Spring and Summer being several days longer than Autumn and Winter (in the Northern Hemisphere).

In popular parlance, the seasons of the northern hemisphere comprise the following months:

Spring March, April, May

Summer June, July, August

Autumn September, October, November

Winter December, January, February

The signs of the *zodiac* for the seasons are given in *Appendix I*.

second (of angle): see *arc-second*.

second (of time): the fundamental unit of time. The accepted scientific definition of the second is now 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels in the ground state of caesium 133. This definition was adopted in 1967 and replaced the earlier (since 1955)

ephemeris second which was defined in terms of a fraction of the mean tropical year in 1900. The above frequency was chosen because it gives a close approximation to the number of seconds in a mean solar day (86,400). Fluctuations in the Earth's rotational rate since about 1969 have been such that the day is now between 1 and 3 ms longer than this number of seconds. These variations are totally insignificant to even the best sundial. The word ~ derives from the Latin 'secunda minuta' or 2nd minute.

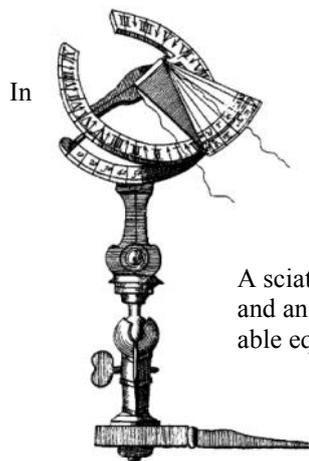
sector: (a) geometrical - the part of a circle cut off by two radii.

(b) - a mathematical instrument comprising two *rules* stiffly-hinged together at one end. They carried scales representing a variety of trigonometrical, dialling, and other functions.

semidiameter (of the sun): [s, S] half the angular size of the sun (or, more correctly, its *photosphere*). As the distance from the Earth to the sun varies during its *or-*

bit, the semi-diameter varies from 15.76 arc-minutes in July to 16.29 arc-minutes in January. dialling, it is usual to take the sun's full diameter as 1/2°.

septentrional: a term now rarely used for 'of



A sciaterra, comprising a trigon and an auxiliary dial on an adjustable equatorial mount.

the north' and sometimes applied to north-facing

dials.

sextant: a navigational instrument for measuring celestial angles, particularly the height (*altitude*) of the sun or fixed stars. So named because its measuring arc is a sixth of a circle; it uses double reflection to allow simultaneous observation of the sun and the horizon at angles of up to 120°.

sextile: (astrology) an *aspect* of 60° or 1/6th of a circle.

sextupla: an old term for the sun's *altitude* when the shadow length is six times the height of a vertical gnomon. See *Appendix XXV*.

shadow: the blocking of illumination (usually *sunlight*) reaching a location by an opaque body. Shadows are usually observed when they are intercepted by a solid surface, but they also exist in space.

shadow sharpener: any of the various devices for sharpening the edge of a shadow, allowing more accurate time readings to be made. Usually a physical addition to the *gnomon* or *nodus*, it casts a secondary shadow, with its own *penumbra*, in which the primary shadow can be located more accurately (although it may have less contrast). The term is sometimes also used to refer to a movable lens which produces an image of the shadow edge.

shadow square: a square (or rectangular) scale often

found on *quadrants* and *astrolabes* which allows the tangent or cotangent of the *altitude* of a celestial body to be found. It is also used for surveying (to find the height of a tower) and is sometimes called a *quadrat*.

shortest day: a term in common parlance, defined as the day of the year with the shortest period from (astronomical) *sunrise* to sunset. It is normally used synonymously with the winter *solstice* although, strictly, it can vary by a day depending on the exact time of the solstice and the relationship between the rate of change of the *EoT* and that of the local sunset/sunrise.

sidereal time, sidereal day: see *time* (types of)

sigil: an inscribed or painted symbol considered to have magical power. The term is sometimes used to refer to the Zodiac and planetary symbols (see *Appendix I* and *Appendix VIII* respectively). From the late Latin sigillum (sign).

signs of the zodiac: see *Zodiac*.

Sirius: (the Dog star) the brightest star in the night sky, used by the Egyptians as a means of determining the beginning of the Nile floods. See *heliacal* rising.

skiaphilist: a term invented by A. P. Herbert (see *Sources*) to mean shadow-lover. From the Greek for 'shadow' and 'I love'.

skylight: light which reaches the observer from the general (blue) sky. It is *sunlight* which has undergone multiple scattering events with the molecules of the Earth's atmosphere (i.e. Rayleigh scattering) or with clouds or other aerosols in the atmosphere. High levels of skylight reduce the *contrast* of a shadow. It also tends to be *polarised*. On a typical cloudless day in the UK, around 20% of the illumination will be skylight.

slant: see *obliquity*.

small circle: a circle on the surface of a sphere whose centre does not coincide with that of the sphere (and hence it must always have a smaller diameter).

Sol: the sun, as a god in Roman mythology. Often used in poetry, mottoes, etc.

solar compass: an instrument for direction finding which uses dialling principles. The most common are modified versions on an *analemmatic dial* with a vertical *gnomon*. Sometimes called an **astro-compass**, although these more properly use sightings of the fixed stars.

solarium: Latin for sundial. Beware, it can also be interpreted as 'sunning place'.

solar longitude: the *ecliptic longitude* of the sun, it varies from 0° (at the vernal *equinox*) to 360° during the year. By *Kepler's Second Law*, the rate of change of the solar longitude is such that the Earth sweeps out equal areas on the ecliptic plane in equal times.

solar parallax: the difference between the sun's *altitude* as observed from the Earth's surface and its true astronomical value from the centre of the Earth. In contrast to atmospheric *refraction*, it causes the sun to appear lower than its true position, but its value is much smaller, reaching a maximum of 9 arc-seconds at the *horizon* and falling to zero at the *zenith*. First measured accurately by *Cassini*.

solar time: see *time* (types of).

solstices: (Summer ~, Winter ~) literally, 'Sun stands

still'. In the Northern hemisphere, they represent the beginning of summer (on or around 21 June) and the beginning of winter (on or around 21 December) respectively. They are (usually) the same as the *longest* and *shortest days*, respectively. Astronomically, they are the occasions (date and time) when the sun's *ecliptic longitude* is 90° or 270°, respectively, and correspond to the extreme values of *declination*.

solstitial colure: (archaic) the *great circle* on the *celestial sphere* which passes through the *solstices* and *celestial poles*. It is one of *Sacrobosco's* celestial circles.

South: one of the *cardinal points* of the compass, it is the direction opposite north, in the direction of the south celestial pole. It is also the direction of the sun at local *noon* (in the northern hemisphere).

southing: another term for a southern *transit*.

South Pole: the location on the Earth's surface where it intersects the *axis*, and opposite the *North Pole*. It has a *latitude* of -90°.

specular reflection: *reflection* from a smooth or polished surface - i.e. mirror-like. The angles of incidence and reflection are equal. Shadows cannot be observed by specular reflection, and hence dials must not have polished dial plates. Contrast with *diffuse reflection*. Partial specular reflection occurs when a surface consists of many small polished facets with a preferred alignment, such as a machined metal surface.

spherical angle: the angle whose vertex is at the intersection of two *great circles* of the *celestial sphere*. Spherical trigonometry deals with spherical angles and triangles.

spherical triangle: the figure formed on the surface of a sphere by three intersecting *great circles*. The **fundamental** (or **nautical**) triangle is the special case of a spherical triangle on the *celestial sphere* with vertices at the *zenith*, *North celestial pole* and the *sun*.

split noon: see *noon gap*.

standard time zone: [TZ] a geographical region which uses a single *civil time*. These are approximately regions between two lines of *longitude*, set 15° apart, and hence with 1 hour time difference between adjacent zones. The standard time for each zone is the *mean solar time* at the central or standard meridian for the zone. For the UK, which is in Zone 0, the standard meridian is the *Prime Meridian* at Greenwich, and the zone nominally extends from 7½° W to 7½° E. For political reasons, other time zones have their boundaries adjusted to follow country borders or other features and there are some half-hour zones. The zones were defined at the same international conference in 1884 that set Greenwich as the Prime meridian. See *Appendix XVIII* for dates of adoption of this system worldwide.

steradian: (pron. ster-ade-e-on) the unit of solid angle. It is the central solid angle of a sphere subtended by a surface area equal to the square of its radius. The whole sphere supports an angle of 4π steradians around its centre.

stereography: (hence **stereographic projection**) a drawing method in which the celestial sphere is projected from a point on its surface to a plane which is tangent to it. Its main property is that circles on the celes-

tial sphere are projected as circles or straight lines on the plane. It is fundamental to the construction of *planispheres* and *astrolabes* as the *plate* is a stereographic projection. It is also the grid in the central section of *Oughtred's double horizontal dial*. Its use is difficult in the construction of standard sundials due to the vast length of some of the radii required (although this can be overcome by calculating in *cartesian coordinates* and then converting). Its use was advocated by 17th century diallists.

string gnomon: a *gnomon* in the form of a flexible cord which is pulled tight when the dial, typically in *diptych* form, is opened.

style: {stile} the line in space which generates the shadow edge used to indicate the time on the *dial plate*. Note that a *gnomon* with finite thickness will have two styles (one along each of the upper edges) which will each be operational for parts of every day. If the *gnomon* is in the form of a long rod, the style will be the virtual line running along the centre of the rod and the dial is read by estimating the centre of the shadow. Note: this modern distinction between *gnomon* and style is not the one found in earlier literature where (from 1577) the word style was used to indicate a polar-pointing *gnomon* (a *polos*) or, more rarely, a *nodus*. Hence **stylar:** pertaining to the style or *gnomon* of a dial (first used 1688).

style height: [SH] of a polar style is the angle that the style makes with the *sub-style* line. Note that this is an unusual use of the word "height", and **style angle** could be regarded as a better term

sub-nodus (point): the point on the *dial plane* that lies perpendicularly below (or behind for a vertical dial) a *nodus*. The distance from this point to the *nodus* is sometimes called the **ortho-style distance**.

sub-style angle: [SD] the angle that the *sub-style* makes with the *noon line*, measured in the same sense as the *hour lines* (towards the p.m. hours for a south-facing vertical dial).

sub-style (line): the line lying in the dial plane which is perpendicularly below (or behind for a vertical dial) the *style*.

sub-style triangle: the right angled triangle formed with the polar *style* as the hypotenuse, with the other sides lying along the *sub-style* and the *ortho-style distance*.

summer solstice: see *solstices*.

sun: the star at the centre of our solar system. The mean distance to the Earth (designated the Astronomical Unit or AU) is 149.6×10^6 km. It has a surface temperature of about 5800 K. The solar spectral irradiance reaching the Earth's surface (at AM1 - air mass 1 - i.e. looking through a standard atmosphere with the sun at the *zenith*) ranges from about 250 nm to 2000 nm, with the main peak at 490 nm. See *semi-diameter* for the apparent size of the sun. In 17th century dialling literature, the term is sometimes spelled 'Sun' or 'sunne'.

sun clock: see *Dial types*.

sun compass: see *solar compass*

sundial: an instrument for indicating the time and/or date from the position of the sun. More generally, it can give any function of the sun's co-ordinates. See *dial* for the origins of the term, and *Dial (types of)* for

types.

sunlight: light reaching the observer directly from the sun. Contrast with *skylight*. Note that the sun's rays reaching the Earth are always taken as parallel, but coming from an extended source (see *semi-diameter*).

sunrise, sunset: the first (last) appearance of the sun above the *horizon* each day. Civil ~ occurs when the sun's upper *limb* appears on the horizon. Note that astronomers define the rising of an object as an altitude of 0°. The difference is due to the combined effects of the sun's mean *semi-diameter* (16 arcmin) and *atmospheric refraction* (34 arcmin). See *Equations* for expressions to calculate sunrise and sunset. In the 17th century, the sun's *azimuth* at sunrise and sunset were sometimes referred to as 'amplitude ortive' and 'amplitude occasive', respectively.

sunshine recorder: a meteorological instrument for recording the hours in which the sun shines. The most interesting type is the **Campbell-Stokes** ~, which uses a spherical lens to focus bright sunlight onto a paper chart, burning a track along it.

superior: refers to an event on the *celestial sphere* above the *horizon*. Opposite of *inferior*.

synodic: pertaining to the successive conjunctions of a planet (or moon) with the sun.

T

tangent line: {contingent} an 18th century term for a line at right angles to the *sub-stylar* line.

tellurian: a demonstration model, similar to an *orrery*, but showing the Earth-Sun system, or the Earth-Sun-Moon system. This latter is sometimes referred to as a **lunarium**. Note: the tellurian is sometimes called a tellurium but this term is best avoided as it is the name of the 52nd element in the periodic table.

terminator: the edge of the shadow cast by a self-shadowing object, such as the edge of the illuminated part of the moon.

terrella: from the Latin for "little Earth". See *globe dials* for the sundial based on a ~. *William Gilbert* also used the term ~ to refer to a spherical lodestone (magnet) used to investigate the Earth's magnetism (see *magnetic variation*).

tide(s): the divisions of a day used in the Anglo-Saxon period. The time from *sunrise* to *sunset* was divided into four tides or time periods. See *Appendix II* for the names of the tides. Lines showing the tides are found on *Anglo-Saxon* and some *mass* dials. Some dials also have lines denoting the half-tide. The term has found its way into more modern English through words such as 'eveningtide'. Note that this use of the word has no connection with the marine tides.

Time, (types of):

Apparent solar ~: the measure of time based on the diurnal motion of the true sun.

astronomical ~ (astronomers' ~): a form of *equal hours* used by astronomers up to 1925. The day was reckoned from noon to noon, starting twelve hours after *Civil time*. Contrast to *ship time*. Do not confuse with *sidereal time*.

British Summer Time: [BST] *civil time* in the UK

during the 'summer', one hour ahead of *GMT*. Invented by William Willett and first introduced in 1916. A sundial showing BST in Petts Wood, near Chislehurst, Kent, is his memorial. BST usually begins on the last Sunday in March, and ends on the last Sunday in October. These dates are now coordinated with Summer Time in the rest of the EU.

civil ~: the legally-accepted time scale in a particular country or region. It is based on the *standard time* for that *standard time zone*, but may have fixed differences (eg *BST*). Measured in *modern hours* from the most recent *midnight*, with either a 24 hour or 2 × 12 hour format.

clock ~: simply the times shown by a clock, usually *civil* time. Hence the appendage "o'clock" to some times.

Daylight Saving Time: [DST] *civil time* during the summer in much of the USA (and some other countries) obtained by advancing clock time one hour from local standard time. Equivalent to *BST* in the UK. *Benjamin Franklin* (1706 - 1790) was one of the first scientists to discuss DST; it was legally adopted in 1918.

dynamical ~: [or Terrestrial Dynamical Time, **TDT**] 'scientific time' – it superseded *ephemeris* time in 1984, and is based on a uniform scale of time derived from atomic clocks (i.e. not subject to fluctuations in the Earth's rate of rotation). Now usually called **international atomic time (TAI)**.

ephemeris ~: [**ET**] 'scientific time' - used between 1960 and 1983, this uniform timescale was based on the *ephemeris second*, itself derived from the period of rotation of the Earth at a particular date. It was succeeded by *dynamical* time when the *second* was redefined in 1984.

French revolution ~: a decimal timescale (10 equal hours or decadays per day) devised in 1790 by the French Academy following the French Revolution. Each hour was divided into 100 millidays (of 86.4 seconds) and each milliday into 1000 microdays (0.0864 seconds each). The decimal timescale, which had been used previously in ancient Egypt and China, was never fully implemented and was quickly dropped, with the result that sundials so calibrated are extremely rare.

God's ~: an 18th and 19th century expression for *solar time* (*L.A.T.*), meant to contrast with man's time (i.e. *clock time*).

Greenwich Mean Time: [GMT] the basis for *civil time* standards worldwide, it is the time at Greenwich as given by the fictitious mean sun. It is derived from *UT*.

Japanese ~: see *Appendix XX*.

Local Apparent Time: [L.A.T.] - the use of the full-stops is encouraged to avoid confusion with the common contraction of 'latitude' this is *solar time*, as derived from the real sun at any particular location. Some authors (non-UK) may refer to it a Local True Time.

local mean ~: {mean ~} [**LMT**] this is *solar time* which has been corrected for the *EoT* but not for *longitude*, so it is still location specific. English

towns used this form of time prior to the coming of national railways and the telegraph, e.g. 'Oxford time'.

Mean Solar Time: the authoritative (by the National Physical Laboratory) definition is: a measure of time based conceptually on the diurnal motion of the fictitious mean sun, under the assumption that the Earth's rate of rotation is constant.

railway ~: (or **London time**) a colloquial term used for Greenwich time as it began to replace local time with the introduction, in the mid-1800s, of railways and the resulting need for unified timetables.

ship ~: an obsolete form of time used by navigators, e.g. Capt. Cook. It was measured in *equal hours* from noon to noon but, in contrast to *astronomers' time*, was always twelve hours ahead of *Civil time*.

sidereal ~: [**τ**, **SDT**] 'star time', as used by astronomers. This is timekeeping based on the *sidereal day*, and hence it runs ahead significantly with respect to solar-based time. Do not confuse with *astronomical time*. **Local sidereal time** is equal to the *hour angle* of the first point of Aries and is, to a first approximation, sidereal time with a *longitude correction*.

solar ~: the same as *Local Apparent Time*.

Summer time: a generic term for *BST*, *DST* etc.

standard ~: [**ST**] is *mean solar time* at the central meridian of a given *time zone*.

universal ~: [**UT or UTC**] this is the basis for terrestrial and civil timekeeping, and was adopted in January 1972. It is tied to the rotation of the Earth, and hence has to be periodically adjusted by the addition of *leap seconds* to account for the gradual slowing of the Earth, and the vagaries of its rotation. UT is by definition measured from the *inferior transit* of the fictitious *mean sun* so that, to a reasonable approximation, GMT = UT and the Greenwich transit occurs at 12:00 UT. The measurement is based on standard *seconds*.

The version referred to as **UTC (Universal Time, Coordinated)** simply means the value averaged over a number of atomic clocks world-wide. In aviation, it is referred to as Z or zulu.

zonal solar time: a modern term used to denote solar time at a *time zone* meridian. Thus it is *local apparent time* with a longitude correction but without *EoT*. In the UK, it would be denoted **Greenwich Solar Time**.

- End of Time (types of) -

time zone: see *standard time zone*.

torquetum: (pron. tor-kwet-um) an early (known to be before 1326 AD) astronomical instrument capable of fixing star positions and producing conversions between equatorial and ecliptical *co-ordinates*. Some forms may have been used to help delineate dials, and torquetum-type dials for solar and *sidereal* time were made in the late 17th century. Most famously, it features amongst the instruments in Holbein's 1533 painting 'The Ambassadors' (National Gallery).

transit: the meridian passage of a celestial body. This occurs when the body is directly south of the observer. It can also refer to the time of this occurrence. Transits

may be either *superior* or *inferior*.

transom: a crosspiece of fixed length, as on a *cross-staff*. Sometimes called a **vane**.

transversals: another term for the *diagonal scale* used to allow interpolation of readings on a scale.

trefoil: an heraldic ornamental design of three leaves or lobes. It is often used on dials to mark the half and/or quarter hour lines. Sometimes it is simplified to just three dots arranged in a triangle.

triangle (fundamental or nautical): see *spherical triangle*.

triens: an extended *quadrant*, with a 120° arc. It can usually indicate the time in both *equal* and *unequal* hours.

trigon: in dialling, a mechanical aid to drawing lines of *declination* on *dial plates*. It consists of an instrument which is fitted to, and can swivel around, the *nodus* on a polar-pointing *gnomon*, and can be set at an angle equal to the sun's declination angle to the gnomon. Often used with an associated *auxiliary* dial. Another form of trigon, dating from the early 19th century, is in the form of *sector* with an extra arm, turning it into an adjustable triangle. Trigon is also an archaic term for a triangle. From the Greek "trigonon" or three-cornered. A further old use of ~ is simply a diagram.

trine: (astrology) an aspect of 120° i.e. a third of a circle.

tripla: an old term for the sun's *altitude* when the shadow length is three times the height of a vertical gnomon. See *Appendix XXV*.

triptych: (pron. trip-tich) literally "three leaves", it refers to a set or *compendium* of three instruments, including at least one dial. Other instruments often include a compass and perpetual calendar.

triquetum: see *Ptolemy's rulers*. Do not confuse with *torquetum*.

tropical year: see *year*.

tropics: geographical bands of the Earth's surface, extending from the equator to latitude 23°26' N (tropic of **Cancer**) or to 23°26' S (tropic of **Capricorn**). The terms are also used to refer to these specific latitudes. Note that they represent the extremes of the region where the sun can reach the *zenith* when the sun's *declination* is at its extreme values.

twilight: the interval after *sunset* or before *sunrise* when

is not completely dark. It is determined by the sun's *altitude* falling within a given range, as follows:

civil twilight: -0°50' and -6°

nautical twilight: -6° and -12°

astronomical twilight: -12° and -18°

These values reflect the need for decreasing light levels for various activities. Twilight is sometimes called 'crepusculum' in 17th century dialling literature.

U

umbra: the central, darkest portion of a shadow, i.e. the region which does not receive direct rays from any part of a distributed light source (e.g. the sun).

umbra recta: Latin for upright (or right) shadow, it is the label often found on the cotangent scale of *altitudes* < 45° on a *shadow square*.

umbra versa: Latin for reverse (or contrary) shadow, it is the label often found on the tangent scale of *altitudes* > 45° on a *shadow square*.

Universal Time (UT): see *time (types of)*.

V

verdigris: (pron. ver-de-gree) the green *patination* found on weathered brass and copper.

vernal {spring} equinox: see *equinoxes*.

vernier: a small moveable scale for obtaining fractional parts of the subdivisions of a fixed scale. Invented by *Pierre Vernier* in 1631 (published Brussels, 1638). For circular scales, a Type A vernier has a central zero. After about 1780, sextants commonly had a Type B vernier with the zero on the right of the scale. Early European instruments often have the very similar *nonius*.

versed sine: {versine} a trigonometrical function equal to (1-cosine) of an angle. Lines of ~ are sometimes found on old *quadrants*, dials and *sectors*. See *Appendix XXVII* to a geometric representation of trigonometric functions.

vertical angle: the angle from the *zenith* to the *horarius circle* passing through the sun, measured along the *prime vertical* (the E-W vertical circle). It is one of the *ptolemaic co-ordinates*.

vertical plane: see *principal plane*.

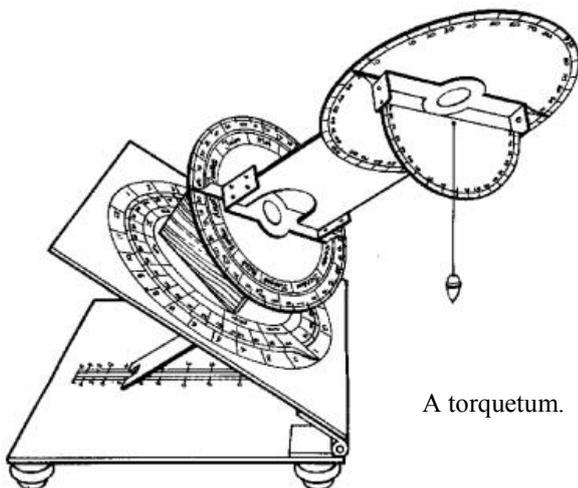
volvelle: (pron. vol-vel) an old device consisting of one or more movable circles surrounded by other graduated or figured circles. It is used for showing the rising and setting times of the sun and moon, the state of the (marine) tides etc. A ~ has sometimes been included around the rod-gnomon of *equiangular* dials.

W

waxing (moon): the *phases* of the moon as the visible crescent grows from the new moon.

waning (moon): the *phases* of the moon as the visible crescent shrinks from the full moon.

wedging out: {canting out} placing wedges between a dial plate and its mounting surface. (a) for a *horizontal dial*: to compensate for moving a dial to a different



the sun illuminates the upper atmosphere and hence it

latitude from the one it was designed for, (b) for a *vertical dial*: to ensure that it faces a *cardinal point* of the compass (usually S).

West: the point on the *horizon* 90° (measured anti-clockwise) from the *north* point. The sun appears to set at the west point at the *equinoxes*.

winter solstice: see *solstices*.

X

Y

year: the time that it takes the Earth to make one orbit of the sun. The **tropical year** is the interval in which the mean *ecliptic longitude* of the sun increases by 360° . This is the version of the year used in normal calendars and has a length of 365.24219 days. Other versions of a year (e.g. the sidereal, anomalistic and Julian years) have differences of about a hundredth of a day to this figure. A **common** ~ is a ~ that is not a *leap year*.

Yule: an ancient Celtic festival held on or around the 21st of December, celebrating the winter solstice. It is one of the *cross-quarter days*, and has now become synonymous with Christmas.

Z

zenith: (astronomical) the point on the *celestial sphere* vertically above the observer. In everyday parlance, ~ usually implies the highest point. This gives rise to confusion as the mid-day sun is often described as its ~, irrespective of the *latitude*.

zenith distance: {**zenith angle**} [z] the complement of the *altitude* i.e. $(90^\circ - a)$

zodiac: an imaginary band, centred on the *ecliptic*, across the *celestial sphere* and about 16° wide, in which the sun, moon and the planets Mercury, Venus, Mars, Jupiter and Saturn are always located. The band is divided in 12 intervals of 30° , each named (the **Signs of the Zodiac**) after the constellation of stars which it contains. The sun's *ecliptic longitude* may be measured against this scale. The names (and/or signs) of the constellations are given in *Appendix I* and are often used in sundials, instead of the date, to specify *declination* lines etc. Because of the effects of *precession* over the period of 2,300 years since the constellations were first named, the signs of the zodiac have slipped by a whole sign, i.e. at the *vernal equinox* (defined as the first point of *Aries*), the sun is actually

in the constellation of Pisces.

Zonwvlak: a major suite of computer programs for calculating sundial lines. Written by Fer de Vries (Netherlands) it is available at www/iaehv.nl/users/ferdv. The name is short for zonnewijzer (sundial) vlak (plane).

SYMBOLS

SYMBOLS

The following symbol set should be used in dialling equations wherever possible. In computer programs and spreadsheets, where Greek symbols cannot be used, the capitalised version should be used instead. The sign conventions and reference points for the various parameters are given in the main glossary.

Preferred symbol	Alternative symbols	Meaning	Dimensions
(a) Co-ordinates on the celestial sphere, etc.			
α	RA	Right Ascension of a celestial body	angle or time
δ	DELTA, DEC	declination of the Sun (or other celestial body)	angle
λ (or λ_e)	ELON	ecliptic longitude of a celestial body	angle
β	ELAT	ecliptic latitude of a celestial body	angle
ε	EPS	obliquity of the ecliptic	angle
e	EC or ε_c	eccentricity of the Earth's orbit	dimensionless
s	S	Sun's semi-diameter	angle
(b) Observer's local co-ordinates			
λ (or λ_t)	LON	longitude (terrestrial) (positive west of Greenwich)	angle
ϕ	PHI, Lat	latitude of a place	angle
h	HA	hour angle (p.m. hours give positive angles)	angle
A	AZ	azimuth of the sun (clockwise from S)	angle
a	ALT	altitude of the sun	angle
z	ZD	zenith distance	angle
η	PA	parallactic angle	angle
(c) Sundial parameters			
d	DEC	declination of a wall (E negative, W positive)	angle
i	INC	inclination of the dial plate (horiz. to back of dial)	angle
v	V	noon line to line of greatest slope for a declining, inclining dial	angle
SH	SH	style height or angle from dial plane (note unusual use of "height")	angle
SD	SD	sub-style angle from noon line	angle
DL	DL	difference in longitude	angle
X	HLA	hour line angle from noon line (positive for pm)	angle
N	NH	nodus height above dial plate (or length of vertical style)	distance
(d) Time related			
E	EoT	Equation of Time (as a time)	time
E_a	EoTA	Equation of Time (as an equivalent hour angle)	angle
t	T	time (subscript shows which system)	time
LAT	L.A.T.	Local Apparent Time	time
LMT	LMT	Local Mean Time (LAT corrected for EoT)	time
ST	ST	Standard Time (LMT corrected for longitude)	time
TDT	TDT	Terrestrial Dynamic Time	time
TZ	TZ	Time Zone number (integer)	dimensionless
t_{sr}, t_{ss}	TSR, TSS	times of sunrise and sunset	time
JD	JD	the Julian Day number	days
τ	SDT	sidereal time	time
ET	ET	ephemeris time (obsolete)	time
UT (UTC)	UT	Universal Time (Co-ordinated)	time
GMT	GMT	Greenwich Mean Time	time
DST	DST	Daylight Saving Time	time
BST	BST	British Summer Time	time

SYMBOLS

Preferred symbol	Alternative symbols	Meaning	Dimensions
(e) Co-ordinate systems			
(x, y)	X, Y	cartesian co-ordinates of a point on the dial plane with respect to the origin (centre) of the dial. Optionally, $(x, y, 0)$ in 3-D.	length, length
(x', y')	X', Y'	Cartesian co-ordinates of a point on the dial plane with respect to the sub-nodus point.	
(r, θ)	R, THETA	polar co-ordinates of a point on a dial plane w.r.t. the origin.	length, angle
<i>hec</i>	HEC	hectemoros angle	angle
<i>hor</i>	HOR	horarius angle	angle
(f) Miscellaneous			
μ	MU	refractive index	dimensionless
R_o	R0	angle of atmospheric refraction	angle
T	TEMP	temperature, absolute (for temperatures given in Celsius, add 273)	Kelvin
P		atmospheric pressure (usually in mb)	$m/l/s^2$

Notes: λ is traditionally used for both terrestrial and ecliptic longitudes. In the rare cases where this could cause confusion, they should be denoted λ_t and λ_e , respectively.

SUNDIAL EQUATIONS

"All this information is secured by means of instruments suitable for these purposes, and by tables and by canons.... For everything works through innate forces shown by lines, angles and figures"
Opus Majus, Roger Bacon (1220-1292).

Sundial equations are of the standard sources. here use the preferred notations of the various scribed in the glossary. They are also self-consistent, and follow the sign conventions of the glossary, i.e. if the correct signs of the angles are input, and proper note is taken of the signs of the trigonometrical functions, the outputs will also have the correct signs.

published in many Those reproduced symbols and defi-parameters as de-

Notes. In the equations for the hour line angle X , the equations are for $-90^\circ < h < 90^\circ$, i.e. between 6 a.m. and 6 p.m. L.A.T. For other times, the true hour line angle is given by:

$$X' = X \pm 180^\circ$$

The hour angle, h , in degrees, is given by

$$h = (T_{24} - 12) \times 15^\circ$$

where T_{24} is the time in 24-hour clock notation (hours after midnight) in decimal hours.

1. Horizontal dial ($i = 0^\circ$)

Style height (in degrees):

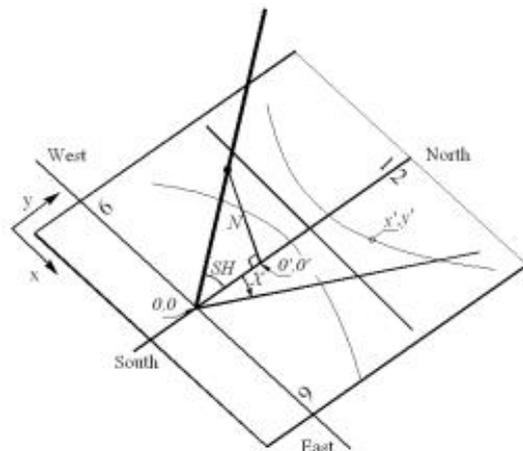
$$SH = \phi$$

Hour line angles (from noon):

$$X = \arctan\{\sin \phi \cdot \tan(h)\}$$

Nodus shadow point (x', y'), measured from the sub-nodus point and given Azimuth A and altitude a

$$x' = +N \frac{\sin(A)}{\tan(a)} \quad \text{and} \quad y' = +N \frac{\cos(A)}{\tan(a)}$$



2. Vertical direct S dial ($i = 90^\circ$)

Style height:

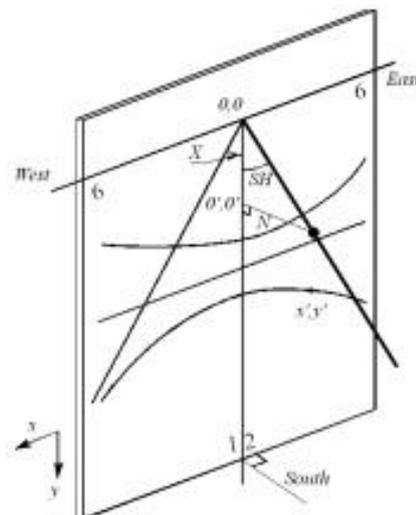
$$SH = 90^\circ - \phi$$

Hour line angles:

$$X = \arctan\{\cos \phi \cdot \tan(h)\}$$

Nodus shadow point (x', y'), measured from the sub-nodus point and given Azimuth A and altitude a :

$$x' = -N \cdot \tan(A) \quad y' = N \frac{\tan(a)}{\cos(A)}$$



3. Declining dial ($i = 90^\circ, d$)

Style height:

$$SH = \arcsin\{\cos d \cdot \cos \phi\}$$

Sub-style angle:

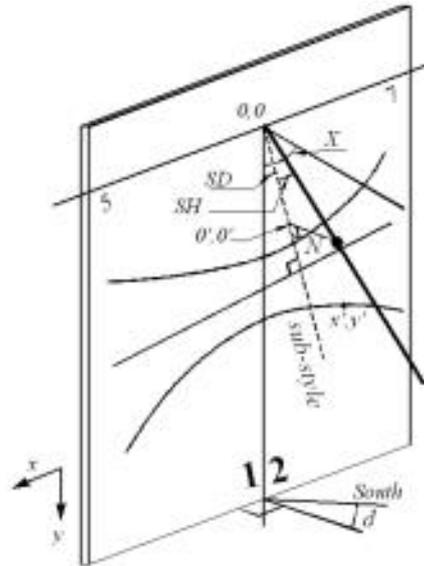
$$SD = \arctan\{\sin d \cdot \cot \phi\}$$

Hour line angles:

$$X = \arctan\left\{\frac{\cos \phi}{\cos d \cdot \cot(h) + \sin d \cdot \sin \phi}\right\}$$

Now (x', y') , measured from the sub-nodus point and given Azimuth A and altitude a :

$$x' = -N \cdot \tan(A-d) \quad y' = N \frac{\tan(a)}{\cos(A-d)}$$



4. Declining-reclining dial

Noon line angle (with respect to the line of greatest slope):

$$v = \arctan\{\tan d \cdot \cos i\}$$

Style height:

$$SH = \arcsin\{\cos \phi \cdot \sin i \cdot \cos d - \sin \phi \cdot \cos i\}$$

Sub-style angle (measured from the noon line):

-style $SD = \arctan[\sin(SH) \cdot \tan(h_s)]$ where h_s is the sub-hour angle given by:

Hour line angles (with respect to the noon line):

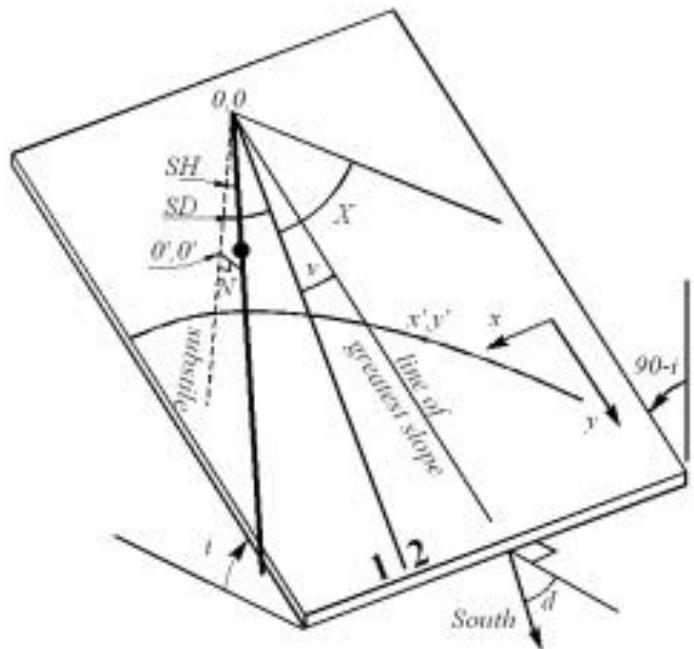
$h_s = \arctan\left[\frac{\sin d \cdot \sin i}{\cos \phi \cdot \cos i + \sin \phi \cdot \cos d \cdot \sin i}\right]$ Nodus shadow point (x', y') , measured from the sub-nodus point and given Azimuth A and altitude a :

$$X = \arctan[\sin(SH) \cdot \tan(h - h_s)] + \arctan[\sin(SH) + \tan(h_s)]$$

where σ is given by:

$$x' = -N \cdot \frac{\cos \sigma \cdot \tan(A-d)}{\sin(\sigma+i)} \quad y' = \frac{-N}{\tan(\sigma+i)}$$

$$\sigma = \arctan\left[\frac{\tan a}{\cos(A-d)}\right]$$

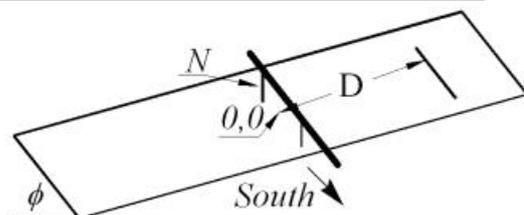


A reclining dial declining towards the East.

5. Polar dial

Hour line distance D is given by:

$$D = N \cdot \tan(h)$$



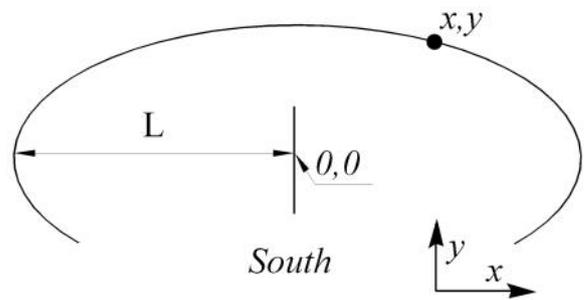
6. Analemmatic dials

For a horizontal elliptical dial with a major (East-West) axis of $2L$, the minor axis (North-South) has a length of $2L\sin\phi$. Then if the hour points have coordinates (x,y) with y increasing towards the North:

$$\begin{aligned} x &= L \sin h \\ y &= L \sin \phi \cdot \cos h \end{aligned}$$

The location of the base of the gnomon for a given date (sun's declination δ) is:

$$\begin{aligned} x &= 0 \\ y &= L \tan \delta \cdot \cos \phi \end{aligned}$$



7. Sun's altitude

The sun's altitude a at any time is given by:

8. $a = \arcsin[\sin \delta \cdot \sin \phi + \cos \delta \cdot \cos \phi \cdot \cos(h)]$ Sun's azimuth

If the sun's azimuth $A \leq 90^\circ$, it may simply be calculated from:

For the general case, the following equations avoid problems of ambiguity with the signs of the trigonometrical functions:

$$\tan(A) = \frac{\sin(h)}{\sin \phi \cdot \cos(h) - \cos \phi \cdot \tan \delta}$$

so that:

$$\sin(A) = \frac{\cos \delta \cdot \sin(h)}{\cos a}$$

$$\cos(A) = \frac{\cos \delta \cdot \sin \phi \cdot \cos(h) - \sin \delta \cdot \cos \phi}{\cos a}$$

$$A = \arctan[\cos A, \sin A]$$

9. Sunrise, sunset

The time (hour angle) of sunrise/sunset is given by:

The azimuth of rising/setting sun is given by:

Note that these times and azimuths are for astronomical sunrise/sunset, i.e.

the $A_{sr,ss} = \mp \arccos\left[\frac{-\sin \delta}{\cos \phi}\right]$ when the centre of sun is on the true horizon, neglecting atmospheric refraction. For other definitions of sunrise/sunset, the corresponding altitudes should be used in the equations of (7) and (8).

10. EoT (best fit equations)

A full calculation of the EoT for any time in any epoch is complex and the reader is referred to Meeus (see *Sources*), an *Astronomical Almanac*, or the *NASS Dialling Companion* computer program. Mean daily values of the EoT (over the period 2000 - 2047) are given in *Appendix XIII*. For many practical purposes, the Fourier transform approximation given below

An expansion as a Fourier series more suitable for the calculation (with computers or calculators) is given below. In it EoT is minutes, the angles are in radians and G is the number of the day : G=1 for 1st Jan, G=32 for the 1st of Feb, etc. The errors are < 18 sec. of time over the period 2000-2047.

$$\begin{aligned} \text{EoT} = & 7.3656 \cdot \cos(0.01720279 \cdot G + 1.511) \\ & + 9.9158 \cdot \cos(0.03440558 \cdot G + 1.9574) \\ & + 0.3060 \cdot \cos(0.05160838 \cdot G + 1.864) \\ & + 0.2026 \cdot \cos(0.06881117 \cdot G + 2.3213) \end{aligned}$$

11. Sun's declination (best fit equations)

The comments made above for the EoT also apply to the sun's declination. The Fourier transform approximation below yields a maximum error of 0.03 degrees (less than 3 arcminutes) or, if the final two terms are omitted, 0.2 degrees (12 arcminutes):

$$\begin{aligned} \delta^\circ = & 0.3831 + 23.26 \cdot \cos(0.01720279 \cdot G - 2.9461) \\ & + 0.3551 \cdot \cos(0.03440558 \cdot G - 3.0316) \\ & + 0.1342 \cdot \cos(0.05160838 \cdot G - 2.5322) \\ & + 0.0326 \cdot \cos(0.06881117 \cdot G + 0.1203) \end{aligned}$$

See *Appendix XIV* for tabulated values.

12. Sun's refraction

This is the $R_o = \frac{1.02}{\tan\left[a_T + \frac{10.3}{a_T + 5.11}\right]}$ is the Bennet-udson formula. R_o is the refraction in arcmins for a temperature of 10°C

and an atmospheric pressure of 1010 mb. For other conditions, a multiplying factor of $0.28P/T$ is required, where P is the pressure in mb and T is the temperature in kelvins (= temp in °C + 273).

Then

$$a_a = a_T + R_o$$

where

a_a is the apparent (observed) altitude in degrees
 a_T is the true altitude

13. Babylonian and Italian Hours

The Babylonian hour t_B and Italian hour t_I (in hours) are given by:

and
$$t_B = \{24 + (h + \zeta)/15\} \text{ mod } 24$$

where $t_I = \{24 + (h - \zeta)/15\} \text{ mod } 24$ h and ζ are in degrees and

14. $\zeta = \arccos(-\tan \phi \cdot \tan \delta)$ Seasonal or Temporal Hours

The temporal hour t_T (in hours) is given by:

If $h < -\zeta$:

$$t_T = \frac{6 \times (360 + h - \zeta)}{(180 - \zeta)}$$

If $h \geq \zeta$:

$$t_T = \frac{6 \times (h - \zeta)}{(180 - \zeta)}$$

Otherwise:

where all angles are in degrees and ζ is as defined for Babylonian hours above.

$$t_T = \frac{6 \times (h + \zeta)}{\zeta}$$

15. Cosine Rule

The relationship in spherical trigonometry which connects the solar co-ordinates is:

$$\sin(a) = \sin \delta \sin \phi + \cos \delta \cos \phi \cos(h)$$

or, using the law of sines:

$$\frac{\sin A}{\cos \delta} = \frac{\sin(h)}{\cos(a)}$$

16. Navigation and bearings

The following equations are approximate in that they assume that the Earth is a perfect sphere. They are sufficiently accurate for calculating the bearings and distances of places for inclusion on dial plates.

Given two locations with latitudes/longitudes of (ϕ_1, λ_1) and (ϕ_2, λ_2) , and putting $\Delta\lambda = \lambda_2 - \lambda_1$

$$\theta = \arctan\{\sin \Delta\lambda, (\sin \phi_1 \cos \Delta\lambda - \tan \phi_2 \cos \phi_1)\}$$

where the arctan is in the range $-\pi$ to $+\pi$ radians, as determined by the (x,y) arguments. The bearing b of point 1 from point 2 in degrees and measured clockwise from the N is then:

$$b = \{450^\circ - \theta^\circ\} \text{ mod } 360$$

The great circle distance D between the two locations is:

$$D = r \arccos\{\sin \phi_1 \cdot \sin \phi_2 + \cos \phi_1 \cdot \cos \phi_2 \cdot \cos \Delta\lambda\}$$

where r is the radius of the Earth (6371km).

BIOGRAPHIES

The following brief biographies includes astronomers, mathematicians, architects, craftsmen and authors worldwide who have contributed to gnomonics. Some of the subjects are better known in other fields, but their contributions to dialling are stressed here. This is by no means a comprehensive list, but does include the most important figures. For a much more comprehensive listing of British dial makers, see:

J. Wilson: 'Biographical Index of British Sundial Makers from the Seventh Century to 1920', British Sundial Society (2003).

Abbreviations:

c. (circa) approximate date.

fl. (flourished) period known to have been working.

d. died.

Spelling:

Individuals names in the period before 1700 showed much variation, even by their owners. Those used here are the ones most commonly found, although some alternatives are shown where known.

Airy, George Biddell 1801-1892: was an English astronomer and Astronomer Royal from 1835 until 1881. Amongst many scientific achievements, he introduced an improved system of *meridian* observation and introduced many new instruments to the Greenwich Observatory, including the Airy transit circle which redefined the *Greenwich Meridian* which, largely through his efforts, was accepted as the *Prime Meridian* in 1884. He introduced the electrical timing of *transits* in 1854, and the daily recording of sunspots using the Kew *heliograph* in 1873. He determined the exact *longitudes* of Paris, Edinburgh, Brussels and Cambridge, helped with the mapping of the Canadian/American border, and assisted in the construction of the clock chimes for the Westminster Tower.

Allen, Elias fl.1606-1654: was the most famous mathematical instrument maker of his day, and is sometimes regarded as the father of the English instrument making industry. He was born in Kent and may have undertaken estate surveys when young. He was first established with a shop in Blackhorse Alley, near Fleet St., London, in 1606-11 but later moved to the Sign of the

Shoe,
He spe-
in instru-
brass
ver, giv-



Horse
Strand.
cialised
ments of
and sil-
ing in-

structions in their use. Allen was the second in a long line of master-apprentice relationships, training under *Charles Whitwell* and with his most notable apprentice being the

renowned *Ralph Greatorex*, leading through *Henry Wynne* to *Thomas Tuttell*. He was a friend of *William Oughtred*, for whom he made *double horizontal* dials and who described him as 'a man well knowne and esteemed by all men of art for his skilfullness in making instruments of metal'. The high quality of his engraving can be seen in his instruments in the British Museum, the Science Museum, London, the Museum of the History of Science in Oxford, the Whipple Museum, Cambridge, and St. Andrews University, Edinburgh.

Abbo of Fleury c.C11: a French Benedictine monk who produced an *horologium* in the late C11 which gave shadow lengths for his location at each hour and for each month.

Adams, George senior fl.1760-1772: was a Fleet St., London, instrument maker. He served his apprenticeship under *Thomas Heath*, and went on to become instrument maker to King George III. He made, for example, a number of large *horizontal dials*. He was succeeded by his sons George jnr. (1750-95) and Dudley (1760-1826).

Albatagnius (or **Abu-'Abdullah Muhammad ibn Jabir Al-Battani**) 858-929: was an Arab astronomer (born Haran, Turkey, died Samarra, Iraq) who refined *Ptolemy's* work with careful measurements, particularly of the length of the year and the *precession* of the equinoxes. He was also a brilliant mathematician who extended plane trigonometry to the surface of a sphere (spherical trigonometry). His work, including the invaluable *cosine rule*, became known in Europe during the Renaissance.

Alhazen (or **Abu Ali al-Hassan ibn al-Haytham**) c.965-1038: was born in Basra (now in Iraq) and was the greatest scientist of the Middle Ages, particularly in the field of optics. He wrote a treatise on Arabic astronomical instruments, including many forms of sundial, and which noted the innovation of a *polar style* to produce *equal hours*. He contested the views of Hero and *Ptolemy* that vision involves rays emerging from the eye, postulating that light originates from the sun or a flame. He made and described lenses and spherical/parabolic mirrors, and measured the *refraction* of light. He also postulated that rainbows are

formed in the atmosphere. His chief work was published in 1572 as 'Opticae Theasurus' from a 13th century Latin translation.

Anaxagoras c.500-428 BC: a Greek astronomer who gave the correct explanation of solar and lunar *eclipses*, hypothesised that the moon is observed by reflected light, and maintained that all heavenly bodies are composed of rocky material.

Anaximander the Elder c.611-547 BC: an Ionian natural philosopher, he helped bring the knowledge of the ancient Egyptians, and others, to Greece. He also introduced the sundial there. This dial with a vertical *gnomon* enabled him to ascertain the lengths and angles of shadows, thereby allowing him to measure the lengths of the *years* and *seasons*, and set the times of the *equinoxes* and *solstices*. He envisaged the Earth as a cylinder(sic) with its axis running E-W, floating in space.

Apian, Peter (or **Apianus** or **Bennewitz**) 1495-1552: discussed *quadrants* in his 'Instrument Buch' of 1533, and also developed the *Apian dial* (a universal *card dial*). Some of his famous dials still exist in Austria.

Apollonius of Perga c.245-c.190 BC: was the last of the great Greek mathematicians. His great work was on the *conic sections*. His work on *epicycles* and *ellipses* formed the basis for *Ptolemy's* cosmology. A sundial named the *arachne* is attributed to him by *Vitruvius*.

Aristarchos of Samos c.320-250 BC: was probably the first astronomer to propose a heliocentric theory of the solar system. This had the Earth and the planets circling the sun, with the stars infinitely distant. He was able to make some (inaccurate) estimates of the sizes and distances of the sun and the moon by noting that the moon must lie at the right angle of a triangle with the sun and Earth when it is half illuminated. The document that describes this, 'On the Magnitude and Distances of the Sun and the Moon', still exists.

Arsenius, Gualterus Regnerus c.1525-c.1580: was a master instrument maker in the Low Countries, who graduated from the university of Louvain in 1546. He often signed himself on instruments as the 'nephew' of the mathematician *Gemma Frisius* and, although it is uncertain if they were actually related, Arsenius certainly succeeded *Mercator* as Gemma's instrument maker. His main output was *astrolabes*, but he also made, for example, a magnificent bowl *scaphe dial* with an astrolabe lid.

Bacon, Roger 1214-1294: was an English philosopher and scientist. He was Franciscan friar educated in Paris and Oxford. At the Pope's request, he wrote a three-volume encyclopaedia on all the known sciences. Although he suffered religious persecution, he developed magnifying glasses, made proposals for a telescope, and promoted the use of *latitude* and *longitude*. He also wrote to the Pope suggesting calendar reform as the *equinox* date was in error by 9 days.

Bede St. (known as the **Venerable Bede**) c.673-735 AD: an English monk, theologian and historian who lived in a monastery at Jarrow, Northumbria. He wrote 'the Ecclesiastical History of the English People' (731 AD), a primary source for English history.

His work 'Horologia' contained tables of shadow lengths for different times of the year, and also compared the day-lengths in Jarrow with those in Italy (though he never travelled far from Jarrow). His 'De temporum ratione' of 725 gave a table of the *paschal* cycle. He wrote in Old English vernacular, and also in Latin, and his work survives through manuscripts copied by his pupils. His Feast Day is 27 May.

Bion, Nicholas fl.1652-1723: a well-known Parisian instrument maker who made many *Butterfield dials* - indeed, he may have originated the style. He also wrote an influential treatise 'The Construction and Principal Uses of Mathematical Instruments' in 1709 (translated into English by Edmund Stone in 1723).

Blagave, John c.1558-1611: a mathematical practitioner from Reading, educated at St. John's College Oxford. He is best known for his 'Mathematical Jewel', which was a uranical *astrolabe*, (using a *stereographic projection*) and was described in a book called 'The Mathematical Jewel' published in English in 1585. It contained much material on dialling and in 1609 he published 'The Art of Dyalling' dedicated to the subject. Being a strong Protestant in this Elizabethan period, he was able to adopt and promote the *Copernican* system. He also designed a map of the world in 1596



(now in the British Museum). His monument, in St. Laurence's church, Reading, features five cherubs each holding a *Platonic solid*.

Bloud, Charles fl. second half C17: was a French dial maker working in Dieppe. He is best known for his *magnetic azimuth dials*, usually in ivory, although he also made standard *diptych dials*.

Bradley, James 1693-1762: was the third Astronomer Royal. He was educated at Balliol College, Oxford, where he studied theology and he was a vicar in Bridstow. He resigned a position as chaplain to the Bishop of Hertford in 1721 to become Savilian Professor of Astronomy at Oxford. Bradley is famous for discovering the *aberration of light* (and hence correctly determining the speed of light), and for accurately describing the *nutation of the earth*.

Brahe, Tycho 1546-1601: often known by his first name only, he was the last of the great naked-eye astronomers. Born of aristocratic parents, he was educated in Copenhagen in law and philosophy, but took up astronomy after observing the 1560 solar eclipse. After working in Basle, King Frederick II of Denmark offered him the island of Hven in 1576 for what is regarded as the first observatory of its kind in the world. Brahe was the last great astronomer to reject the heliocentric theory of *Copernicus*, although he did suggest

that the planets other than the Earth revolved around the sun. His carefully prepared tables of the motion of the sun allowed him to determine the length of the year to within a second, making calendar reform inevitable. Tycho moved to Germany in 1597 and took as his assistant *Johannes Kepler*. Kepler made great use of Tycho's data. Brahe was also an instrument builder,

producing advances in a number of instruments, including an important instrument for quadrants.

Butterfield, Michael

fl.1674 born in Paris at age.

work-

Armes d'Angleterre', and was, uniquely, granted his own coat of arms. He has given his name to the portable *Butterfield dial*, although he was not the only maker and probably was not the originator. As his workmanship was of the highest quality, many other makers signed their dials 'Butterfield à Paris'.

Briggs, Henry (1561-1630): was the Savilian Professor of Geometry at St. John's College, Cambridge, and the first holder of the chair of geometry at *Gresham College*. He was a colleague of *Gunter* and worked with *Napier*, producing tables of logarithms to base 10 in 1617. He made the famous sundials on the east buttresses of the Merton College, Cambridge, chapel, which still exist.

Cassini, Giovanni Domenico (or *Jean Dominique*) 1625-1712: was a brilliant Italian-born astronomer who moved to France in 1669 to set up the new Paris Observatory. Before moving, he had been Professor of Astronomy at Bologna University, and had set up the great *meridian line* of San Petronio in 1653, allowing him to publish accurate tables of the sun in 1662. Although a well-regarded observational astronomer who had influence with the Pope and the French King, he was slow to adopt the *Copernican* system and insisted (wrongly) that the earth was flattened at the Equator, despite arguments from *Newton* and *Huygens*. He was the head of a dynasty of four generations of astronomers at the Paris Observatory.

Chaucer, Geoffrey c.1342-1400: was an English poet and author. His most famous work, 'Canterbury Tales', includes at least one reference to a sundial - the *chilindrum*. It is also cited as the first occurrence of the phrase 'of the clokke' (*o'clock*), showing that *equal hours* were already becoming known. The prolog to the Parson's Tale relates shadows and time in a manner consistent with *equal hours*. Additionally, he wrote a treatise on the *astrolabe*.

Clavius, Christopher c.1580: an Italian astronomer



working in Rome. He published 'Gnomonices Libri Octo', a complete synthesis of the theory and practice of gnomonics. He did much of the work that led to the *Gregorian* calendar reform.

Cole, Humphrey (or Humfray Colle or a bewildering number of variants on his instruments) c.1525-1591: is the best-known of the Elizabethan instrument makers, with examples of high quality workmanship being found in many museums. Born in the north of England, he moved to London and was probably a member of the Goldsmiths' Company. He was an assistant at the Mint in 1564 and set up his own workshop 'near the North door of St.Paul's'. It is possible that he was a student of *Nicholas Kratzer*. He made principally *quadrants* and *rules*, often incorporating dials. There are also existing examples of *horizontal*, *ring* and *equinoctial dials*. His masterpieces include the two-foot *astrolabe* dated 1571 at the University of St. Andrews and the mis-named 'Drake's astrolabe' (*compendium*) at the National Maritime Museum.

Copernicus, Nicholas (Mikolaj Kopernigk) (1473-1543): was a Polish astronomer and cleric who was responsible for finally overturning the geocentric theory of the cosmos. He was educated at Krakow and Bolgna, and spent most of his working life as the Canon of Frombork. He only made a small number of astronomical observations, relying on other people's data. His model of the planets orbiting the Sun, with the axis of the Earth tilted by 23.5°, was largely correct, although he retained the system of epicycles. His ideas were first formulated and circulated in 1513 and 1530, but publication of his master-work 'De Revolutionibus Orbium Coelestrium' was delayed until he was on his deathbed. It remained on the Roman Catholic Church's index of forbidden books from 1616 until 1835.

Culpeper, Edmund 1660-1738: There were actually two Edmund Culpepers (father and son) together with a grandson Edward. They were all accomplished instrument makers; a signed *horary quadrant* with a sundial on the reverse is in the Whipple Museum, Cambridge.

Daniel, Christopher St. J.H. 1933- : was one of the founders of the BSS, and is its current chairman. After a career at sea and as a curator at the National Maritime Museum, Greenwich, he is now a freelance sundial designer. His most notable dials include the famous 'Dolphin dial' at the National Maritime Museum, and the four vertical dials on St. Margaret's Church, Westminster. He is also author of the Shire book 'Sundials' which has helped to re-popularise the subject in the UK.

Democritus c.460-c.370 BC: was a Greek philosopher (born in Thrace) who travelled to Egypt and the East. He is mainly remembered for introducing the term 'atom' for tiny indivisible particles which make up the whole universe. He also drew the first maps with rectangular grids i.e. an early form of *latitude* and *longitude* and wrote a treatise 'Polographié' on the *polos*.

Drecker, Joseph c.1925: A German historian, author and scholar, he wrote the influential and rather mathe-

mathematical 'Die Theorie der Sonnenuhren' including the definition of *planetary hours* used here.

Dyson, Frank Watson 1868-1939: was an English astronomer educated at Trinity College, Cambridge. He was Astronomer Royal for Scotland (1906-1910) and for England (1910-1933). His main area of research was stellar motion but he was also deeply interested in solar phenomena, being actively involved in two solar *eclipse* expeditions, including Arthur Eddington's famous one which confirmed the General Theory of Relativity. Dyson was also passionately interested in time measurement and initiated the first public broadcasting of time signals by the BBC over radio - the familiar six-pip signal.

Emerson, William 1701-1782: was an English mathematician and teacher who lived at Hurworth, County Durham, where at least one of his dials can still be seen. His tomb is in the churchyard and the village pub, the Emerson Arms, is named after him. His 'Dialling, or the Art of Drawing Dials...' was published in 1770 and gave a good description of geometrical dialling.

Emilianus, Palladius c.C5: wrote 'De Re Rustica' in about 450 AD. This *horologium* gave the shadow lengths in Sicily for every hour of the day for each month, and was much used by scholars such as *Bede* and *Abbo of Fleury* in future centuries.

Eratosthenes c.276-c.194 BC: a Greek scholar and polymath, born in Cyrene (now part of Libya). He was appointed as the librarian of the famous museum of Alexandria in 235 BC. He is best known for measuring the circumference of the Earth by means of the difference in noon shadow lengths from a vertical gnomon in a hemispherical bowl between Alexandria and Syene. His value of 46,500 km compares quite well with the modern figure of 40,075 km at the Equator. Eratosthenes also managed to measure the *obliquity of the ecliptic*, obtaining a value of 23° 51', and introduced the concept of the tropics, temperate zones, and polar regions.

Evans, Lewis: a collector of portable dials and astrolabes in the early 20th century. One of his forebears had been an assistant at the Greenwich Observatory. In 1924 he donated his collection to be the foundation of the Oxford Museum of the History of Science.

Fale, Thomas c.1555-c.1610: a Caius College, Cambridge, mathematician, credited with publishing the first work in English devoted to dialling. It is 'Horologigraphia: the Art of Dialling', completed 1586 and first published 1593. This was substantially a translation from the Latin of Wittekind's treatise of 1576.

Ferguson, James 1710-76: was sent to Edinburgh University by patrons. He became a prolific writer and lecturer in natural philosophy, able to make his own apparatus and instruments. He wrote specifically for the non-mathematical public. His main contribution to dialling was the publication in 1770 of 'Lectures on select subjects: with the use of Globes, the art of dialling, etc.' A signed instrument engraved 'The Universal Dialling Machine and Solar Time-Finder' is at The National Maritime Museum.

Finé, Oronce (or Orontius Finaeus) 1494-1555: was the diallist to Francis I of France. He published a number of books of solar horology (e.g. 'Protomathesis', 1532). He was an approximate contemporary of *Nicholaus Kratzer*, and performed a similar rôle as Kratzer's for the English king. He was an astrologer as well as an astronomer and mathematician, and was jailed in 1518 for an unpopular horoscope. An ivory *navicula* signed by him still exists. He produced a world map which coined the named 'Terra Australia', and wrote on the use of lunar *eclipses* to determine *longitude*.

Flamsteed, John 1646-1719: the first Astronomer Royal of England. In 1665, at the age of 19, he made the first accurate tables of the *Equation of Time* in England - 'De Aequatione Dierum' (published in 1669). He was educated at Jesus College, Cambridge, and was also a clergyman with the living of Burstow, Surrey. He became King Charles II's 'Astronomical Observer' at the newly established Greenwich Observatory in 1675. He was a fastidious observer who invested heavily in the best instruments available. His book 'Doctrine of the Sphere' in 1680 gave a new determination of the solar *eccentricity* at almost its true value



0.01675. He made a precise determination of the *latitude* of Greenwich, the *obliquity of the ecliptic*, and the position of the *equinoxes*. He also produced tables of atmospheric *refraction*, tidal tables, and supervised the compilation of the first table describing the inequality of the lunar ecliptic following *Kepler's second law*. Flamsteed's main body of work, including star maps and detailed observations, was only published posthumously ('*Historia Coelestis Britannica*' in 1725, and '*Atlas Coelestis*' in 1729), despite the fact that they were needed by his contemporaries *Isaac Newton* and *Edmond Halley*. He probably never made a sundial, although his papers show that he had dial construction in mind and he certainly corresponded with dial makers, particularly in his early years.

Foster, Samuel c.1600-1652: was an English mathematician and astronomer, and was amongst the first-rank of 17th century diallists. He was born (probably) in

Coventry and educated at Emmanuel College, Cambridge. After a period teaching in Coventry, he became the Professor of Astronomy at *Gresham College*, London, in 1636. As a Puritan, he suffered persecution, forcing him to return to Coventry between 1637 and 1641. He published 'The Art of Dialling' in 1638, providing the first printed account of the use of Latitude and Hour *scales* for dial design. At this stage the scales were drawn out on a *quadrant*, rather than the ruler-like layout adopted by George Serle. The book also introduced the *prosthaphaeretical arc* for solving the *spherical triangle* when constructing *inclining/declining* dials. Foster constructed a *geographical dial* of great complexity on the internal wall of the astronomy professor's chambers at *Gresham College*. Following his death, several books were published from Foster's manuscripts. These included 'Elliptical or Azimuthal Horologigraphy' (1654) which had three important sections. One of these developed the mathematics of the *analemmatic dial* for the first time in English. The second considered dials on arbitrary planes with movable styles, now known as *Foster-Lambert dials*. The third deals with rectilinear or the *diametral* designs not covered elsewhere.

Fourier, Jean Baptiste Joseph 1768-1830: was a French mathematical physicist who was principally interested in heat. His mathematical methods for harmonic analysis, called fourier analysis (and f. series, integrals, transforms etc.) are now widely used to describe mathematical functions, e.g. the *EoT*.

Franklin, Benjamin 1706-1790: the famous American President and scientist, he showed a great interest in dialling. In a humorous essay, he proposed a form of *noon gun* with an different number of canon on each hour line. He also strongly championed the use of *Daylight Saving Time*.

Galileo (properly, **Galileo Galilei**) 1564-1642: one of the greatest scientists ever, he was born in Pisa (where he famously demonstrated the acceleration due to gravity) but he also worked in Florence and Padua. He discovered the isochronal properties of the pendulum, invented the thermometer and was one of the earliest users of the refracting telescope. This he improved and developed to study the surface of the moon and to discover the satellites of Jupiter, which he suggested could be used to measure *longitude*. His 'Siderius Nuceus' (Starry Messenger) of 1610 showed the 'imperfections' of the heavens, and brought him into conflict with the Church. The imperfections included sunspots, which moved with time. After the new Pope Urban VIII was elected, Galileo published his 'Dialogue Concerning the Two Chief World Systems' in 1632, clearly favouring the *Copernican* system. The book was banned and Galileo convicted of heresy, dying later under house arrest and reportedly muttering 'Yet it does move'.

Gatty, Margaret (Mrs Alfred Gatty) 1809-1873: a Victorian author on a wide variety of subjects, famous amongst diallists for her book 'The Book of Sundials', first published in 1872. The first edition consisted mainly of dial *motatoes*, but later editions (by her

daughter H.K.F. Eden and Eleanor Lloyd, but still referred to as 'Gatty') carried much more material.

Gemini, Thomas (T.G. or Tc on dials) c.1515-62: a map engraver (trained with *Mercator*) and instrument maker from Flanders who migrated to London around 1540. A superb calligrapher and engraver, he made extant astrolabes and quadrants: one of the earliest known English horizontal dials (in the Science Museum) is dated 1551 and attributed to him.

Gemma Frisius, Regnier (or Regner, Reiner) 1508-1555: was born in Friesland in the Low Countries (hence his nickname) and became a professor of medicine and mathematics at the University of Louvain. He cooperated with his student *Mercator* in the construction of maps, globes and astronomical instruments. These included the form of *astrolabe* named after him and which he described in 'De Astrolabio' in 1556, a new *cross-staff*, and both terrestrial and celestial globes. In his 1530 book 'De Principiis Astrono-



miae Cosmographicae' he showed theoretically, for the first time, how *longitude* could be found with an accurate clock and also described the method of trigonometric surveying.

Gibbs, George c.1880-1947: was a consulting engineer and astronomer from Yorkshire. He was at one time the Director of the Jeremiah Horrocks Observatory, Preston. He is best known as the designer of the high-quality Pilkington & Gibbs *heliochronometer*, marketed from around 1906 until the First World War. He later fell out with his financial partner William Pilkington. A Foucault pendulum which he set up is in the Preston Museum.

Gibbs, Sharon L: a modern historian whose 1976 treatise 'Greek and Roman Sundials' is the standard text on the subject.

Gilbert, Sir William 1544-1603: the physician to Elizabeth I and an early physicist, admired by *Galileo*. Born in Colchester, Essex (where his house Timperlys is now a clock museum and features a horizontal dial outside). He described the newly-discovered *magnetic*

variation and described making metal magnets in his 1600 treatise 'On the magnet'. He was also the first Englishman to accept the astronomical system of *Copernicus*.

Greatorex, Ralph (or Gratrix) fl.1654-1712: was a London mathematical instrument maker and surveyor. He served his apprenticeship under *Elias Allen* and later took over his business. He was a friend of both *William Oughtred* and Samuel Pepys, for whom he made several instruments. He made portable dials amongst many other instruments. There is a horizontal string-gnomon dial by Greatorex in the Horniman Museum (London).

Gregory, James 1638-75: a professor at St Andrews and Edinburgh, he was a famous mathematician (discovering an infinite series that sums to pi) and astronomer. He is best known for inventing the Gregorian (reflecting) telescope in 1661. He employed men such as John Knibb and *Henry Wynne* to furnish the Observatory at St Andrews, and the *meridian line* in the Long Gallery of the university library at St Andrews is attributed to him.

Gunter, Edmund 1581-1626: was born in Hertfordshire and educated at Christ Church, Oxford. He taught mathematics for some years before becoming the third Professor of Astronomy at *Gresham College* 1619-26; he was also a Rector in Southwark (1615-26). He designed a large and complicated sundial for the King's Privy Garden at Whitehall; the dial was demolished in 1697, though Gunter's descriptive book of 1624 survives. In orientating the dial with John Marr by use of a magnetic compass, *magnetic variation* was discovered. He also developed the Gunter *quadrant* and a precursor to the sliderule. He published seven-figure tables of logarithms, sines and tangents in 'Canon Triangulorum' (1620) which also coined the terms cosine and cotangent and the contractions sin and tan.

Halley, Edmond (or Edmund) 1656-1742: an English astronomer, best known for describing the orbit of the comet named after him. He studied at Oxford and although he did not obtain a degree he published a book on *Kepler's Laws*. He made an expedition to St. Helena to study the southern skies, and was appointed as the second Astronomer Royal in 1720. He was a friend of *Newton*, being partly instrumental in getting him to publish the 'Principia'. He had wide scientific interests, publishing papers on the rainbow, tides, magnetism etc. He made a study of *Ptolemy's* writings and hypothesised that the apparent position of the stars had altered over the 15 centuries since the original observations had been made. Although he is not known to have had a direct input to dialling, his work at that period had a great influence on the underlying principles.

Hawney, William fl.1710-50: was a mathematics teacher from Lydd in Kent. He undertook land-survey, supplied sundials and quadrants for house and garden as well as teaching the whole range of simple practical mathematics and the use of mathematical instruments. According to custom he made his teaching notes into books. 'The Doctrine of Plain and Spherical Trigo-

nometry' (1725) contains 87 pages devoted to 'Dialling, Arithmetical and Instrumental, on all sorts of Planes'.

Heath, Thomas fl.1714-1765, d.1773: a celebrated London mathematical instrument maker who was born in Luton and apprenticed to *Benjamin Scott*. He later went into partnership ('Heath and Wing') with his son-in-law, the mathematical practitioner, surveyor and almanac maker *Tycho Wing (Jnr)*. Amongst his other apprentices were *George Adams* senior and John Troughton. A famous Heath dial is at Penshurst Place, Kent. He is particularly well known for his large *universal equinoctial ring dials*.

Herschel, Frederick William 1738-1822: was originally a German musician but emigrated to Britain in 1757 and became a celebrated astronomer and the foremost telescope maker of his time. In 1800 he examined the solar spectrum using prisms and thermometers, discovering the existence of the infrared solar energy. By using *Maskelyne's* data, he established for the first time that the sun was not fixed in the universe, and he was also able to measure the sun's velocity relative to seven bright stars. His house in Bath is now a museum, and has an *armillary sphere* in the garden.

Hevelius, Johannes (or **Hewel** or **Hewelcke**) 1611-1687: a German astronomer, mostly famous for his careful charting of the moon. Between 1642 and 1645 he produced a fairly accurate value for the period of the solar rotation, and gave a good description of the structure of sunspots, coining the term 'faculae'. His observations of the sun over this period are detailed in an appendix to his 'Selenographia'.

Hipparchus c.190 BC- after c.126 BC: a great Greek astronomer and mathematician, born in Nicaea (now in Turkey). His star maps (using a system of *celestial latitude and longitude*) were of great accuracy for their time, were extensively copied by *Ptolemy*, and were used much later by *Halley*. From the movements of the star Spica over 150 years, he deduced a value of around 45 arc-seconds for the annual *precession of the equinoxes* (cf. the modern value of about 50.26"). He measured the length of the tropical *year* as 365¼ days and obtained a value of the lunar period which was only 1 second too short. Despite these accuracies, Hipparchus accepted the notion of a geocentric universe, with the Earth not quite at the centre of the sun's orbit. He also contributed in the field of mathematics with one of the earliest formulations of trigonometry.

Horne, Dom. Ethelbert 18xx-19xx: was an English priest who lived and worked at Downside Abbey, Somerset, for most of his life. He published extensive reviews of *mass dials* - 'Primitive sundials or scratch dials' in 1917 and 'Scratch dials - their description and history' in 1929.

Huygens, Christiaan 1629-1695: the most famous Dutch astronomer, mathematician and physicist. He invented the accurate pendulum clock and produced the first accurate table of the *Equation of Time* in 1665. He republished this table in his 'Horologium Oscillatorium' in 1673.

John of Holywood: see *Sacrobosco*.

Jackson, Joseph fl.1735-1760: was an important mathe-

matical
ment
who
member
Guild of
cers and
his ap-



instru-
maker
was a
of the
Gro-
served

prenticeship under *Thomas Heath*. One of his horizontal dials can be seen at Wandlebury, Cambs.

Kepler, Johannes 1571-1630: was a German astronomer who is famous for *Kepler's laws* of planetary motion. His interest in astronomy was sparked by the Great Comet of 1577. As a Lutheran, he suffered with religious persecution throughout his life and went to Prague as *Tycho Brahe's* assistant in 1600. Kepler completed Tycho's observations after his death (the celebrated *Rudolphine Tables* of 1627) and made use of them to formulate his laws of planetary motion. His first two laws were published in his 'Astronomia Nova' of 1609. By postulating elliptical orbits, he finally broke the *Ptolemaic* cosmos and provided a firm footing for the *Copernican* one. His 'Mysterium Cosmographicum' had earlier (1596) shown that the five *Platonic* solids (regular polyhedrons) could be fitted inside a series of spheres to match the distances of the planets from the Sun (within 5%). Kepler also wrote the first science fiction book, 'Solemnium', in which a man travelled to the moon.

Kircher, Athanasius fl.1636-1646: was a polyglot Jesuit priest who lived with his students in the Collegio Romano, Rome. His magnum opus 'Ars Magna Lucis et Umbrae' (The great art of light and shadows) shows designs for many complex dials, some of which were not previously known and some of which (e.g. magnetic gnomons, light projection with sound and fire) are fanciful. He is credited by some authors with the introduction of the *signs of the zodiac* on *declination lines*. Some of his dials were made as the 'Sciatheric Tables'; four table-tops made of slate.

Kratzer, Nicholas (or **Nicholas**) c.1487-1550: born in Munich, Bavaria, he studied at the University of Cologne and at the Carthusian Monastery of Maurbach, near Vienna, where he learned his dialling skills. He came to the court of King Henry VIII in 1517/8 as an astronomer and 'deviser of the king's horologies', and as tutor in Sir Thomas More's household. He also entered Cardinal Wolsey's service, lecturing at Oxford at Corpus Christi College (1521-24). Only four dials can definitely be attributed to Kratzer. One is a small gilt brass octagonal dial now in the Oxford Museum of the History of Science. A stone dial, made in 1520 but rejected as incorrectly made, was found as part of a wall and is now in the City of Bristol Museums and Art

gallery. The two others, now lost, were a pillar dial at St. Mary's Church, Oxford - the source of inspiration for the famous Turnbulb or 'Pelican dial', and a multiple cube dial at Christ Church College. This latter dial has recently been used as the basis for David Brown's prize-winning dial, also at Christ Church. Kratzer is famously depicted, together with numerous dialling instruments and partially completed dials, in the 1528 portrait by Hans Holbein (the Younger), currently in the Louvre, Paris. A 1520 portrait by Albrecht Dürer has been lost.

Lalande, Joseph Jérôme le François de 1732-1807: was a French astronomer famous for his planetary tables, his account of the transit of Venus, and his measurement of the distance of the moon using terrestrial *parallax*.

Lambert,

Henri
hann
rich)
1777:
in pov-
the Al-
was a
taught
matical
He
in Swit-
and
ny (for
peror of
as a
tutor.



Jean
(or Jo-
Hein-
1728-
was born
erty in
sace and
self-
mathe-
prodigy.
worked
zerland
Germa-
the Em-
Prussia)
private

He was a multi-talented scholar, publishing on mathematics, physics, astronomy and philosophy. He is remembered amongst diallists for devising a form of analematic dial with a circular scale (the *Foster-Lambert dial*) and for *Lambert's circles*. He also developed (1772) several map projections still used today, including a conic projection and the Universal Transverse *Mercator projection*.

Leybourn(e), William 1626-1716: principally a London-based publisher, he was also an author and mathematical practitioner. His first work dedicated to dialling, in 1669, was 'The Art of Dialling: performed geometrically by scale and compasses; arithmetically by the canons of sines and tangents; instrumentally by a trigonal instrument.....'. It became a standard work, and the third edition in 1721 was called 'Dialling Improv'd'. His great work on dialling was 'Dialling: plain, concave, Convex, projective, reflective, refractive.....'. He was a contemporary of *John Flamsteed* and *Henry Wynne*.

Mach, Ernst 1838-1916: was an Austrian physicist, now remembered for the Mach number, describing supersonic velocities. Amongst his many interests, he investigated the stimulation of the retinal field with spatial patterns and discovered the strange visual effect now called *Mach bands*. This was subsequently forgotten and rediscovered in the 1950s.

Maskelyne, Rev. Nevil 1732-1811: an English astronomer and the fifth Astronomer Royal. He studied divin-

ity at Trinity College, Cambridge, but went to the Greenwich Observatory instead of taking up a living. Although recently portrayed as the villain in the battle with John Harrison to win the *Longitude* prize (he was both a competitor and, later, a member of the Longitude Board), he was a talented astronomer who made strong contributions to the study of *transits*. His most enduring legacy for diallists is the Nautical Almanac which he founded in 1767, comprising a compendium of astronomical tables and navigational aids, including many of his observations of the sun, moon, planets and stars. He also observed the proper motion of several stars, and made measurements at a mountain in Perthshire to determine the gravitational constant.

Melville, Richard (sometimes Melvin) fl.1840-1871: a well known and prolific maker of quality decorative dials, he originally worked from Belfast and Edinburgh, but came to England at a later date. He is particularly known for his multi-gnomoned horizontal dials, usually in slate.

Mercator, Gerardus 1512-1594: was a Flemish engraver, cartographer, astronomer, instrument maker etc. He studied mathematics and philosophy at the University of Louvain, and made a living from making and selling *quadrants*, *astrolabes*, *armillary spheres* and *sundials*. He is now most remembered for devising the *Mercator projection*, introduced in his masterpiece map of the world in 1569 and still much used in map making. Several sundials were built in Rupplemonde, Belgium, to celebrate the quatercentenary of his death.

Meton 5th century BC: was a famous Greek astronomer who worked in Athens. Together with Euctemon, he made a series of observations of the *solstices* and, in 432 BC, derived a calendar with a 19-year cycle - the modern *metonic cycle*. This may have been based on earlier developments in Mesopotamia. He also built a water clock at Colonus, and developed the *parapegma*.



Molyneux, William (1656-1698): was an FRS and a gifted amateur astronomer, working from Trinity College, Dublin. He corresponded with *Flamsteed* and published his '*Sciothericum Telescopicum: a new contrivance...*' in 1686 describing a combination of dial and telescope. It also included his own version of the

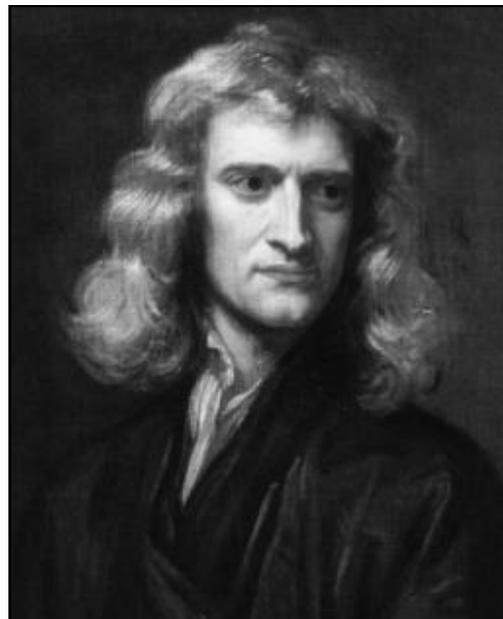
EoT.

Müller, Johannes: see *Regiomontanus*.

Napier, John 1550-1617: was an aristocratic Scottish mathematician and amateur scientist, famous for the invention of logarithms, a term which he derived from the Greek words 'logos' and 'arithmos' (expression, number). He devised these because of the difficulty in performing astronomical calculations involving sines, which were well tabulated. The first logarithm tables were published in his '*Mirifici Logarithmorum Canonis Descriptio*' in 1614, although it was only with collaboration from *Henry Briggs*' that the standard base-ten form was published in 1617. '*Napier's Bones*' were a primitive mechanical computer and comprised numbered rods, usually of boxwood or ivory, which allowed multiplication to be easily performed and square roots to be found. Napier is also credited with the introduction and popularisation of the decimal point.

Newton, (Sir) Isaac 1642-1727: was the foremost British scientist of all time and is often credited with inventing the 'scientific method'. His birthplace, where he performed his most inspired work in the annus mirabilis of 1665, was Woolsthorpe Manor, Lincolnshire which is now owned by the National Trust. He was educated at Trinity College, Cambridge, where he was made Lucasian Professor of Mathematics at the age of 26. He invented a reflecting telescope in 1673, and gave a good explanation of the causes of the rainbow, later published in his opus '*Opticks*' in 1704. His major work is generally called the *Principia* ('*Philosophiae Naturalis Principia Mathematica*') and was published in 1687 after much prompting and financial support from *Edmund Halley*. In it, Newton described the inverse square law of gravitation, his laws of motion, and set the foundation for the mathematics of calculus. He made two scratched dials as a boy at Woolsthorpe Manor; one is now in the library of The Royal Society, London, and the other is inside Colsterworth church (Lincolnshire). Various other dials, notably the celebrated one at Queens' College, Cambridge, have been ascribed to him, almost certainly erroneously.

Ni-



cholson, Peter 1765-1844: was an English mathematician, born at Prestonkirk in Haddingtonshire. He was largely self-taught. He was one of the leading intellects behind 19th century building technology. In 1833 he wrote 'A Treatise on Dialling: one showing the geometrical and the other the arithmetical construction....'. He drew many dials for the Newcastle and Morpeth area in it.

Nonius (Filde Nunez Salaciense) 1502-78: was a Portuguese mathematician and astronomer who, around 1540, devised the idea of engraving an *astrolabe* with a series of concentric circular scales (a '*nonius*') to allow accurate determination of an angle. He also discovered that the *loxodrome* on the current maps described a spiral and not a circle.

Oughtred, Rev. William 1573 (or 1575) - 1660: (pron. Owt-red) was an English mathematician, educated at King's College, Cambridge. He taught at Albury near Guildford for most of his life. His '*Clavis Mathematica*' (the key to mathematics) became the standard mathematics textbook. He showed an interest in dialling early in his career, inventing an easy method of geometrical dialling as an undergraduate. He is most famous for his *Double Horizontal dial*, often referred to as an Oughtred dial, incorporating a projection of the celestial sphere and a vertical style to function as an astrolabe. He designed a popular form of *universal equinoctial ring dial*, and also produced a circular slide rule. He collaborated closely with *Elias Allen* and was also a friend of *Ralph Greatorex*.

Ozanam, Jacques 1640-1717: was a French mathematician and member of the Royal Academy of France. His four-volume '*Récréations mathématiques et phy-*



siques' (1694) gives comprehensive instructions for dial designs and, in improved form and translated into English, was reprinted as late as 1840.

Parent, Antoine 1666-1716: was a French mathematician, born in Paris. In 1701 he demonstrated the possibility of constructing a 'universal' form of the *analemmatic dial*.

Plato (real name Aristocles) c.427-c.347 BC: was a highly influential Greek mathematician and philosopher who founded a school of learning which rejected

practical experimentation in favour of mathematical and intellectual harmony. His insistence in the perfection of the heavens, with the planets moving in circles around the earth, held back astronomy for centuries.

Pliny, Gaius Plinius Secundus AD 23-79: known as Pliny the Elder to distinguish him from his nephew, the biographer. Pliny was a Roman military officer who retired to become an author and scientist. All the important assumptions from classical astronomy are described in Book II of his '*Historia Naturalis*'. This contains his own views together with, for example, the theories of *Hipparchus* and *Eratosthenes*. He expounded a geocentric universe, with the Earth as the pivot for the heavens and the seven planets (Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn). The sun was seen as the ruler of the heavens and had a zodiacal orbit around the Earth, divided into 12 equal parts. The sun was allowed 360 days to complete its circuit, with a surplus 5¼ added to bring it back to the 'same' position in the heavens. Although he had no idea of celestial distances, Pliny judged that the sun was much larger than the Earth, and lay at a great distance, by the fact that the shadows of rows of trees are parallel, and that during the equinoxes the sun reaches the vertical simultaneously 'for all the inhabitants of the southern region'.

Ptolemy, Claudius Ptolemaeus c.90-c.170 AD: was an astronomer, astrologer, geographer and philosopher, probably of Egyptian extraction. He worked at Alexandria (then under Roman domination), with access to the famous library there with its works by *Plato*, *Hipparchus*, *Aristarchos* etc. His master-work was the famous '*Almagest*', which influenced astronomical and religious conceptions for at least 13 centuries, despite the serious errors which it propagated. Ptolemy's cosmos was geocentric with all the orbits being perfect circles, although not always centred on the Earth. He made much use of epicycles, where the planet rotates around a small circle, which itself rotates around a larger one. Ptolemy also drew maps of Asia and Africa in his collection '*Geography*', which included notes on *latitude* and *longitude* which much later influenced Christopher Columbus. His astrological treatise '*Tetrabiblos*' has had a deplorable long-term effect. The *Ptolemaic co-ordinates* are named after him.

Regiomontanus 1436-1476: was a great German astronomer and mathematician who made observations, compiled astronomical tables, assisted in the reform of the *Julian calendar* and was also an active diallist. He was born Johannes Müller in Königsberg, (the king's mountain) which he latinized for his name. He studied in Vienna, where he translated *Ptolemy's* '*Almagest*' from Greek into Latin for his posthumous '*Epitome*', which also included criticisms of Ptolemy's theories which later influenced *Copernicus*. In 1467 he started compiling astronomical and trigonometrical tables, giving celestial co-ordinates which were useful for latitudes up to 60° N and calculating sine tables (which were not published until 50 years after his death). In 1471 he moved to Nuremberg, where he installed a printing press in his house allowing him to publish his

own 'Ephemerides' - giving the positions of the heavenly bodies for every day between 1475 and 1506 - as well as scientific works from other authors. Regiomontanus had a strong influence on the Nuremberg group of diallists and dial makers, and described a universal form of *card dial* in his publication 'Quadratum horarium generale' of 1474. He travelled to Rome in 1475 to assist in amending the notoriously incorrect Julian calendar, but died there (probably of the plague) the following year.

Richard of Wallingford c.1292-1336: was an Oxford mathematician and astronomer. He made scientific instruments, probably including an astrolabe and the famous astronomical clock at the abbey of St. Albans, where he became Abbot. He is thought to have suffered from a form of leprosy, as extant paintings show him with a spotted face.

Rohr, René R-J 1905-1999: was born in Strasbourg and had a long naval career, becoming a captain. He was Honorary Vice-President of the BSS, and wrote many articles on gnomonics. His book on dialling, 'Les Cadrons Solaires' has been translated into English, German and Italian, is still in print and is valuable to modern diallists.

Rowley, John fl.1698 d.1728: was a London instrument maker who turned to large engineering projects after about 1715. He built the first *orrery* for the Earl of Orrery, for whom he also made a *Butterfield dial* (in the National Maritime Museum, together with another for the first Duke of Marlborough). He made two large (29 inch) horizontal dials in 1710 for St. Paul's Cathedral and a set of four for Blenheim Palace, the latter comprising a *double horizontal*, a *geographical*, an *equation* and a *moon dial*. The dial at Cranbury Park, Otterbourne, which is sometimes attributed to *Newton*, is by Rowley. A characteristic of many of his dials is the use of *transversals*, which he may have introduced to dialling.

Sacrobosco, Johannes (also known as **John of Holywood**) c.1195, d. between 1244 and 1256: was an astronomer and mathematician who was born in Yorkshire (probably Halifax) and studied at Oxford. He became a professor and taught in Paris. He was one of the first Europeans to use the astronomical writings of the Arabs, and translated *Ptolemy's* 'Almagest'. His 'Tractatus de Sphaera' (commonly known as the Sphere) dealt with the spherical Earth and the heavens, defined the *celestial equator*, the *ecliptic* and *zodiac*, the length of the day and night at different *seasons* and '*climates*' and also gave a (poor) description of the motion of the sun and moon. The Sphere was published in 1220 and remained the basic astronomy textbook until the 17th century, despite numerous errors. Sacrobosco wrote 'De Anni Ratione' in 1232, describing many forms of time and declaring that the Julian calendar was 10 days in error (which he proposed correcting by omitting one day in 288 years). He also wrote on the quadrant in 'Tractatus de Quadrante'.

Sawyer, Frederick W III 1950-: is a co-founder of the NASS and its current President and Editor. He is a graduate of Yale and Pittsburgh universities, where he obtained B.A. and M.A degrees in Mathematics, Phi-

losophy, and History and Philosophy of Science. He has authored more than 65 articles on dialling and is the inventor of the *Equant dial* and the *Ptolemaic coordinate* category of dials. He is an expert on the work of *Samual Foster* and has done much original work on dialling theory.

Scaliger, Joseph Justus 1540-1609: was a French scholar and Calvinist who found many supposed errors in Pope Gregory XIII's calendar. In 1583 he devised his own calendar of 7980 astronomical years, counting a day at a time, which is now the basis of the *Julian Day* count.

Scott, Benjamin fl.1712- d.1751: was a London mathematical instrument maker who moved to the St. Petersburg Academy of Sciences (Russia) in around 1747. He served his apprenticeship under James Anderton and *John Rowley*, and worked in the partnership of Scott & Price 1714-18. He wrote 'The Description and Use of an Universal and Perpetual Mathematical Instrument' in 1733. He made ring, inclining and garden dials and also globes. He also made a magnificent French *double horizontal* dial, now in the Paris museum of science.

Seller, John Snr. fl.1658-1698: a compass, instrument and dial maker, who was also a surveyor and notable mathematical practitioner. He is one of the few makers of *double horizontal* dials. He taught and wrote on the arts of navigation and gunnery, published 'Praxis Navigation' in 1669, was appointed Hydrographer to His Majesty the King, and made measurements of *magnetic variation* at Wapping.

Serle, George: a C17 mathematical practitioner who produced the first set of *dialling scales* on a ruler and described them in a 1657 instruction booklet 'Dialling Universal'.

Singh, Maharaja Jai 1688-1743: an Indian Maharaja and astronomer, he is best known for the series of five monumental naked-eye observatories that he built at various sites in India. The first was at Delhi (1724) but the most famous is at *Jaipur*, where the 'Brihat Samrat Yantra' was until modern times the largest sundial in the world. Singh also wrote a two-volume treatise on the *astrolabe* entitled 'Yantra Raj Karika'.

Sosigenes 1st century BC: was an Alexandrian astronomer to the Egyptian court who wrote several books about the stars (now lost). He strongly influenced the Roman Julius Caesar to reform the calendar (see *Julian calendar*) in 46 BC.

Sutton, Henry fl.1637 d.1665: one of the best-known 17th century instrument makers, best known for his *horary quadrants* and *ring dials*.

Tompion, Thomas 1638-1713: the leading clockmaker of his day, working from London. He made the two 'Great Clocks' or astronomical regulators for *John Flamsteed* at the Royal Observatory. Amongst his sundials are a famous pair dated c.1690 at Hampton Court, one of them a *double horizontal*. The other dial was copied in 1959, and is at Kew (where the original was from 1832 to 1959). Two portable dials by him, in silver and gold, are in the British Museum. He was one of the earliest adopters of the *EoT* for his clocks and

dials.

Tuttell, Thomas fl.1695-1702: was instrument maker to the king. He trained under *Henry Wynne* and made and sold *Serle's* dialling scales in 1700. He popularised a combination of portable horizontal and analemmatic dials which is self-orientating.

Tycho: see *Brahe*.

Ulugh Beg 1394-1449: a Mongol prince and Muslim of Tartar descent and the grandson of Tamerlane. He built a monumental observatory at Samarkand (now Uzbekistan). It included a huge stone sextant with a radius of 48m with which he could measure to 10 arcminutes and determine the length of the solar year to a minute of time. The remains of the instrument are still extant and his results were used by *Flamsteed*.

Vernier, Pierre 1584-1638: was a French engineer and instrument maker who devised the precision *vernier scale*. He worked as a military engineer for the Spanish Hapsburgs and the rulers of Franche-Comté, and devised his scale after studying the work of *Nonius*.

Vitruvius Pollio, Marcus fl. 46-30 BC: a Roman soldier (served with Julius Caesar in Africa) and architect. In his retirement, he wrote 'De architectura' which was much translated and very influential in Renaissance Europe. It included two chapters of information on the 13 kinds of sundial, and sundial construction methods, then known.

Waugh, Albert E 1903-1985: the Provost and Vice President of the University of Connecticut (USA), he is best known to diallists as the author of the 1973 classic 'Sundials: their theory and construction' which is still in print. Waugh had a library of early dialling books (including *Fale* and *Ozanam*), which he bequeathed to the Homer Babbidge Library of his university, where he is commemorated by a *pillar dial*. He also designed many dials, including two at Connecticut's Mystic Seaport.

Wheatstone, Sir Charles 1802-1875: a British physicist whose name is best remembered for the Wheatstone bridge, an electrical circuit which he did not invent himself. He was a Professor of Experimental Physics at King's College, London, working initially in acoustics but also in optics and electricity. His contributions to dialling were the invention of the *polarised light sundial* (1848), and a precision *heliometer*: examples of both are in the Science Museum, London. He also contributed considerably to the demise of the sundial through his pioneering work with William Cooke to develop a commercial electric telegraph, which was used to distribute *railway time*.

Whipple, Robert: a great collector of early scientific instruments - particularly portable dials and microscopes - in the early 20th century. He was the managing director of the Cambridge Scientific Instrument Company and donated his instrument collection as the foundation of the Whipple Museum of the History of Science, Cambridge in 1944.

Whitwell, Charles c. 1568-1611: was originally trained as an engraver of maps etc. but went on to become the founder of a long line of instrument makers at the Grocers' Guild. He had *Elias Allen* as an apprentice and worked 'without Temple Barre against St. Clement's

Church', London. Numerous instruments, including sundials and *compendia*, are in major museums (including the British Museum and Science Museum).

Wing, Tycho fl.1751 – d.1776: was a mathematical instrument maker who served his apprenticeship under *Thomas Heath* and later went into partnership with him. Several high-quality horizontal dials signed "Heath and Wing" are recorded.

Wren, Sir Christopher 1632-1723: is best known as the English architect responsible for St. Paul's Cathedral, London, and the Greenwich Observatory (1675). He also had numerous mathematical and astronomical interests, having invented an astronomical instrument at the age of twelve. In his second year as student at Wadham College, Oxford, he had translated into Latin a treatise on dialling by *William Oughtred*. Additionally, he had devised a *mirror sundial* for the ceiling of his college rooms. Wren's best-known dial is the magnificent 1658 vertical decliner, now found on the south wall of the Codrington Library at All Souls' College, Oxford. It was originally positioned centrally on the south wall of the chapel in the Front Quadrangle, having been removed during 1869. In its original position, the dial with its *diagonal scale* could be read to one minute.

Wright, Thomas fl.1718- d.1767: held the appointment of Mathematical Instrument Maker to His Majesty the Prince of Wales, later George III, and was the leading maker of his day. He served his apprenticeship under *John Rowley*. One of his horizontal dials can be seen at Lacock Abbey, Wilts.

Wynne, Henry (or Wynn) 1640-1709, fl.1654-1709: a London instrument maker who served his apprenticeship to *Ralph Greatorex* and later numbered *Thomas Tuttell* and Richard Glynne amongst his apprentices. He is noted for his magnificent *double horizontal* dials, such as the one at Drumlanrig Castle. He is also known for his ring dials, and the small book he produced explaining them as well as *moon dials*. In 1677 Wynne made the magnetic *dip* needles with which Henry Bond's *longitude* solution was tested. Wynne is also attributed with introducing the domestic barometer.

Biographies

Date	Development	Date	Development
9000 BC to 8000 BC	A marked bone (possibly) indicating months and lunar phases in use in Ishango (Zaire)	250 BC approx	Catania, Sicily, and hence had the wrong latitude for Rome. Conical forms of <i>scaphe dials</i> first appear in Greece.
4228 BC to 2773 BC	The Egyptians institute a 365-day calendar. The start of the year, coinciding with the annual Nile floods, is linked to the rising of <i>Sirius</i> (the Dog Star) in line with the sun.	240 BC to 230 BC	<i>Eratosthenes of Cyrene</i> (now Libya) calculates the circumference of the Earth from the difference in latitude between Alexandria and Aswan, using shadow lengths. He also lays down lines of longitude on a map.
1500 BC to 1450 BC	L-shaped sundials used in Egypt.	190 BC to 180 BC	The Greek astronomer Seleucus is the last known astronomer to champion a heliocentric theory of the solar system until <i>Copernicus</i> .
1450 BC to 1400 BC	Stonehenge achieves the form known today.	164 BC	<i>Pliny</i> records that Marcus Philippus sets up a sundial properly for the first time in Rome, and the Romans begin to divide the period of daylight into hours.
1292 BC	Pharaoh Seti I dies in Egypt. His cenotaph contains instructions for constructing and using a sundial.	160 BC to 140 BC	<i>Hipparchus of Nicaea</i> (now Turkey) produces a more accurate theory of the <i>precession of the equinoxes</i> .
730 BC	The "miracle of Ahaz" is performed in Judaea by the prophet Isaiah. (see under <i>Ahaz, Dial types</i>)	120 BC to 110 BC	<i>Hipparchus of Nicaea</i> (Turkey) uses a total solar eclipse and parallax to measure the distances to, and the sizes of, the Moon (correctly) and the Sun (an order of magnitude too small).
600 BC to 590 BC	Sundials are used in China and the Chinese text "Arithmetic classic of the gnomon and the circular paths of the heaven" contains a version of the Pythagorean theorem.	87 BC	A complex mechanical Greco-Egyptian astronomical calendar is made and shipped to Rome. It is later recovered from the sea and becomes known as the Antikythera mechanism.
586 BC	Pharaoh Psammeticus erects an obelisk in Heliopolis (Egypt).	52 BC	Chinese astronomer Ken Shou-Ch'ang builds a form of <i>armillary</i> ring, a metal circle representing the equator and used to observe the stars.
585 BC	Thales of Miletus (now in Turkey) is said to have correctly predicted a solar eclipse.	50 BC to 41 BC	Andronikos Kyrresthes builds the Tower of the Winds in Athens. It includes early sundials in the eight principal directions. The Roman architect <i>Vitruvius</i> (Marcus Vitruvius Pollio) includes information on sundials in his "De Architectura" on engineering and architecture. He uses the word <i>analemma</i> in referring to a form of <i>orthographic</i> projection.
520 BC to 510 BC	<i>Anaximander</i> introduces the sundial to Greece (previously used in Mesopotamia, Egypt and China. He also produces a cylindrical model of the Earth.	10 BC	Augustus erects the obelisk of Psammeticus II as a monumental sundial in Rome. The 15 metre stone obelisk gnomon, brought from Egypt and now in the Piazza de Popolo, commemorated victory over Mark Antony and Cleopatra, and was surrounded by numerous lines for the hours, days and months. This <i>pelekinon dial</i> was mentioned by <i>Vitruvius</i> .
500 BC to 490 BC	The Pythagoreans (Greece) introduce a spherical model of the Earth.	46 BC	Julius Caesar, acting on the advice of Greek astronomer Sosigenes (court astronomer of Egypt), introduces the <i>Julian calendar</i> . To account for previous errors, year 46 BC has 445 days.
480 BC to 470 BC	Greek philosopher Oenopides calculates that the axis of the Earth is tipped over by 24° from the plane of its orbit.	84 AD	Fu An and Chia Kuei improve on the <i>armillary sphere</i> for locating stars by com-
420 BC approx	Greek philosopher <i>Democritus</i> draws the first maps with rectangular grids, an early form of <i>latitude</i> and <i>longitude</i> . He also writes on the <i>polos</i> .		
350 BC approx	Berosus the Chaldean (Babylonian) is credited with inventing the <i>hemicyclium</i> .		
340 BC to 330 BC	Kidinnu (Babylonia) works out an (inaccurate) version of the <i>precession of the equinoxes</i> .		
300 BC approx	A cylindrical dial with a polar <i>style</i> is created in Afghanistan. It is believed to be the earliest such dial known.		
270 BC to 260 BC	<i>Aristarchus of Samos</i> (an Aegaeon island) challenges Aristotle's theory by asserting that the Sun is the centre of the solar system and the planets revolve around it. He estimates the distances of the Moon and (wrongly) the Sun from the Earth.		
264 BC	The first dial is set up in the Roman Forum by Valerius Messala. It was brought as booty of the First Punic War from		

Date	Development	Date	Development
	binning an equatorial ring with an ecliptic one.		trigonometry and the <i>cosine rule</i> .
100 to 109	Bhaskara measures the diameter of the sun. Menelaus of Alexandria's "Spherics" establishes spherical trigonometry.	890 to 900	Thabit Ibn Qurra (Baghdad) writes the manuscripts "Description of the figures formed by the extremity of a gnomon in its passage on a horizontal plane, in all the days, in all the places" and "Book on the instruments which indicate the hours, called solar dials".
140 to 149	<i>Ptolemy</i> (Claudius Ptolemaeus) the last great astronomer of the Alexandrian school in Egypt, writes the book "Megale Syntaxis tes astronomias" (Great Astronomical composition) later called the <i>Almagest</i> by the Arabs. It includes his model of the solar system based on circles and epicycles.	940 to 950	The Dunhuang star map is produced in China. It uses a form of projection later used by <i>Mercator</i> .
325	The Council of Nicea formulates the rule for the date of <i>Easter</i> .	1000 to 1010	Ibn Yunus's "The large astronomical tables of al-Hakim" contains accurate astronomical and mathematical tables based on 200 years of observations.
450 approx	Palladius Rutilius Taurus Emilianus in Sicily writes "De Re Rustica", giving shadow lengths for this southerly location.	1010 to 1029	<i>Alhazen</i> (b. Basra, Iraq; d. Cairo) explains the cause of <i>twilight</i> as <i>atmospheric refraction</i> , develops quartz lenses and discovers the properties of parabolic mirrors.
497	Aryabhata I (in India) recalculates Greek measurements of the solar system. He largely accepts <i>Ptolemy's</i> model, but also proposes that the Earth rotates.	1070 to 1090	Arzachel suggests that planetary orbits are <i>elliptical</i> .
529	St. Benedict (c.480-543) founds the Monastery of Monti Cassino in Italy and codifies the seven times of the day when prayers are to be said (the <i>canonical hours</i>)	1086	Chinese scientist Shen Kua's "Dream pool essays" contains the first known reference to a magnetic compass for navigation.
530	Simplicius of Cilicia comments on Plato's theory that the heavenly bodies have uniform circular motions.	1092	In China, Su Sung builds a giant water clock and mechanical armillary sphere.
580 approx	Gregory of Tours writes "De Cursu Stellarum" (The tracks of the stars) providing monks with a set of rules for saying their nocturnal prayers.	1100 approx.	Omar Khayyám (Persia, c1048-1131) calculates the year length correct to about 1 minute.
606	Pope Sabinianus becomes Pontiff and later issues a declaration that all churches should have sundials.	1100 to 1110	Chinese astronomers build a stone <i>planisphere</i> of the heavens that correctly demonstrates the cause of solar and lunar <i>eclipses</i> .
664	The Synod of Whitby, attended by <i>Bede</i> and other leading monks, determine the inaccuracies in the current calendar. The term "Anno Domini" (in the year of Our Lord) is introduced.	1126	Adelard of Bath (England) translates Al-Khwarizmi's "Astronomical tables" from the Arabic.
670 to 679	The <i>Venerable Bede</i> , writes on the calendar, marine tides and the shape of the Earth in his English history "Historica Ecclesiastica gentis Anglorum". He also gives a reasonable table of shadow lengths.	c.1185	The first translations of <i>Ptolemy's</i> <i>Almagest</i> into Latin (via Arabic) appear in Europe.
700 approx	The oldest surviving Anglo-Saxon sundials in England are built at Bewcastle (Cumbria) and Escomb (Co. Durham).	1200-1300	Returning Crusaders bring Islamic knowledge of the polar gnomon and many dial types to Europe.
807	Einhard's "Life of Charlemagne" provides the first Western reference to sunspots	1220	At the University of Paris, John of Holywood (<i>Sacrobosco</i>) writes "Sphaera mundi" (spheres of the world) explaining <i>Ptolemy's</i> <i>Almagest</i> to Europe and explaining solar and lunar eclipses.
827	Egyptian astronomer and geographer Afragamus (Abu-al-'Abbas al Farghani) presents <i>Ptolemy's</i> works clearly in Arabic.	1265-7	<i>Roger Bacon</i> , writes on many subjects including astronomy and astrology, and proposes the need for calendar reform to Pope Clement IV.
850 approx	The "Tiberius Horologium" is written by monks in northern England, giving accurate shadow lengths at different times throughout the year.	1270 to 1280	Kuo Shou-Ching builds the first <i>torquetum</i> , the first astronomical device to use an equatorial mounting.
880 to 910	Arabian astronomer <i>Albategnius</i> re-calculates the length of the year and provides a refined measurement of the <i>precession of the equinoxes</i> . He also develops spherical	1276	Chinese astronomer Zhou Kung sets up a 12 metre gnomon for measuring the sun's shadow.

Date	Development	Date	Development
1280	Abul Hhasan al Marrakushi writes a manuscript (translated into French by J. J. Sedillot in 1834) describing many types of dials and the methods for calculating them.	1517	<i>Nicholas Kratzer</i> comes to England from Austria to be horologist to King Henry VIII. He later makes several famous dials and is painted by Hans Holbein making a polyhedral dial.
1288	Jacob ben Machir ibn Tibbon (Latin name Profatius, 1236-1305) designs a new <i>quadrant</i> or "quadrans novus" which allows the time to be found by the altitude of the sun or another star.	1525	<i>Petrus Apianus</i> publishes his book "Cosmographie" It includes a drawing of a universal diallist's companion, a form of analogue computer for giving sunrise/sunset times, declinations etc. He supports the Aristotelian model of crystal spheres carrying the Sun, Moon and planets. A separate treatise on the construction of dials is published by the artist Albrecht Dürer.
1290 to 1299	William of Saint-Cloud determines the <i>obliquity</i> of the ecliptic from the sun's position at the <i>solstice</i> – he is only 2 arc-mins in error.	1530	<i>Gemma Frisius'</i> globe manual "De Principiis Astronomiae et Cosmographiae" describes the use of spherical gnomon for providing equal hours.
1296	Deng Fung (China) erects a monumental <i>meridian line</i> with a large stone tower.	1531	The first work on modern gnomonics in Europe, "Compositio Horologiorum" is published. It is written by Sebastian Münster, sometimes called the Father of Gnomonics, and describes all the types of dial then in use.
1310 to 1319	The first mechanical clocks appear in Europe and <i>unequal hours</i> begin to be displaced by <i>equal hours</i> .	1532	<i>Oronce Finé</i> (Paris) publishes his "Protomathesis", giving a comprehensive treatment of dial types.
1330 approx.	<i>Richard of Wallingford</i> constructs an astronomical clock for the abbey at St. Albans.	1533	Dutch geographer Reiner Gemma is the first to point out that comparisons of clock and solar time can be used to find <i>longitude</i> .
1348 to 1364	Giovanni de Dondi of Padua (Italy) builds his famous Astrarium, or astronomical clock. Using Ptolemaic astronomy, it shows the orbits of the Sun, Moon and the five known planets, together with many other features including sunrise and sunset.	1550	Joanne de Rojas develops the universal astrolabe, based on the orthogonal projection.
1391	<i>Geoffrey Chaucer's</i> "A treatise on the astrolabe" shows how this instrument can compute the position of a star. He describes a monk using a chilindrum (<i>shepherd's dial</i>) in his "Canterbury Tales".	1560	<i>Oronce Finé</i> (Paris) publishes "De Solaribus Horologiis".
1428	<i>Ulugh Beg</i> measures the length of the year accurate to 58 seconds.	1581	In Rome, Christopher Clavius publishes Gnomonics Libri Octo, a complete synthesis of the theory and practice of gnomonics.
1438	The " <i>horary quadrant</i> " is invented by Johannes von Gmunden (1384-1442) as a simplified version of the old Islamic quadrant specifically for time-telling.	1582	Pope Gregory XIII reforms the calendar, resulting in 1582 having only 355 days. The <i>Gregorian calendar</i> is adopted by most of mainland Europe.
1471 to 1474	<i>Regiomontanus</i> (b. Johann Müller (1436-76) and adopted the name "the man from the Royal Mountain" from his birthplace in Königsberg) builds an observatory in Nuremberg, Germany. He publishes "Ephemerides astronomicae", although it is not until later editions that the tables of <i>solar declination</i> used by navigators (including Christopher Columbus) are included. His "universal rectilinear analemma" is a form of <i>card dial</i> . The Nuremberg group make much use of <i>Ptolemy's rulers</i> , and further develop the <i>torquetum</i> .	1852	Henri III, King of France, regulates the trade of Cadranier - maker of sundials. The resulting corporation developed primarily in Paris in the rue du Cherche Midi.
1475	The Italian mathematician and astronomer Paolo Toscanelli installs a 100 metre <i>meridian line</i> in Filippo Brunelleschi's newly completed dome of the Santa Maria del Fiore, Florence.	1583	<i>Joseph Justus Scaliger</i> (Lot-et-Garonne, France) devises a system of counting days from 4713 BC, later to be incorporated in the <i>Julian Day</i> count.
1493	Possibly the oldest dial with a polar gnomon in Europe is placed on the cathedral of Strasbourg. It is known as "L'astrologue au cadran"	1586	Pope Sisto V, aided by Egnazio Danti, has an <i>obelisk</i> erected in the centre of Plaza St. Peter as part of a <i>meridian</i> still visible today.
1514	<i>Copernicus</i> writes the first version of his heliocentric theory, although it is not published until 1543.	1593	<i>Thomas Fale</i> publishes "Horologigraphica: The art of Dialling", the earliest work devoted to the subject of making dials in the English language.
		1595	<i>Mercator's</i> "Atlas sive cosmographicae" is published posthumously.
		1595	Capt. John Davis invents a form of <i>backstaff</i> .
		1598	Valentin Pini discusses <i>Ptolemy</i> and introduces an armillary dial

Date	Development	Date	Development
1606	<i>Elias Allen</i> , one of the greatest dial and scientific instrument makers of the era, is established near Fleet Street, London.	1740	The modern figure-8 form of the <i>analemma</i> curve is conceived by Jean Paul Grandjean de Fouchy, secretary of the Académie des Sciences, Paris.
1609	<i>Kepler's</i> "Astronomia nova" contains his views that the planets orbit the Sun in ellipses, sweeping out equal angles in equal time intervals (<i>Kepler's Laws</i>). <i>Galileo</i> builds his first telescope	1748	<i>James Bradley</i> discovers the <i>nutation</i> of the Earth's axis.
1624	<i>William Oughtred</i> devises the double horizontal dial, manufactured to very high quality by <i>Elias Allen</i> .	1748	Pope Benedict XIV has the <i>obelisk</i> of Caesar Augustus (originally Psammeticus II) erected in the Piazza del Parlamento. The commemorative plaque still exists.
1631	French engineer <i>Pierre Vernier</i> invents the <i>vernier</i> scale.	1749	Jean le Rond d'Alembert gives the first mathematical description of the regular changes in the Earth's rotational axis.
1633	The Roman Catholic Inquisition forces <i>Galileo</i> to recant his Copernican view that the Earth orbits the sun.	1750	The <i>Greenwich Meridian</i> is established very near its current position by <i>Bradley</i> . It had initially been 20.4 metres further west.
1638	<i>Samuel Foster</i> , of <i>Gresham College</i> , London, publishes "The Art of Dialling", including the first description of <i>scales</i> for drawing a dial.	1752	Great Britain finally adopts the Gregorian calendar, and moves the start of the civil year to 1 January from 25 March. <i>Johann Tobias Mayer</i> (Marbach, Germany) publishes lunar <i>ephemeris</i> with sufficient accuracy to find <i>longitude</i> .
1646	<i>Athanasius Kircher</i> produces the first written description of the <i>ceiling (reflection) dial</i> .	1754	<i>John Dollond</i> (London) invents the <i>heliometer</i> and uses it to find the <i>semidiameter of the sun</i> .
1654	<i>Samuel Foster</i> describes a number of new types of dial, including <i>analemmatic</i> and <i>diametral</i> .	1756	<i>J. J. de Lalande</i> (Ain, France) restores the oldest <i>analemmatic dial</i> still in existence, in Brou churchyard.
1655	<i>Gian Domenico Cassini</i> builds the great <i>meridian line</i> in Bologna cathedral with which he measures new values for the <i>obliquity of the ecliptic</i> .	1759	<i>John Harrison</i> completes his "Number Four" clock, later used to win the Longitude prize.
1657	<i>George Serle</i> puts <i>dialling scales</i> onto a ruler and describes them in his article "Dialling Universal".	1764	<i>Lagrange</i> explains the <i>libration</i> of the Moon.
1664	René Descartes' "Le Monde", published posthumously, affirms the Copernican theory.	1767	Astronomer Royal <i>Nevil Maskelyne</i> publishes the first annual <i>ephemeris</i> which will later become the "Nautical Almanac".
1665	<i>Christiaan Huygens</i> produces the first accurate table of the <i>Equation of Time</i> , later republished his "Horologium Oscillatorium" in 1673.	1784	The first national mail coach service starts in England. Its rigid timetable begins to show the weakness of local time.
1670	G. Mouton proposes the use of one-sixtieth part of a degree of the meridian as the unit of length.	1792	<i>Jean-Baptiste Delambre</i> and <i>Pierre Mechain</i> measure the arc of the <i>meridian</i> from Dunkirk to Barcelona, leading to the new definition of a metre.
1675	The Greenwich Observatory is founded by King Charles II. <i>John Flamsteed</i> is the first Astronomer Royal and calculates a table of the <i>EoT</i> .	1792	The <i>obelisk</i> of Psammeticus II is installed in the Piazza Montecitorio in Rome by order of Pope Pius VI.
1685	<i>John Twysden</i> publishes his "Use of the Great Planisphere called the Analemma".	1812	<i>Laplace</i> gives an accurate calculation for sunrise, using 5000 years of data.
1685	The repeal of the Edict of Nantes results in the exile of many of the diallists who had made Dieppe famous for its sundials.	1816	The <i>mean time</i> of Paris becomes the official time of metropolitan France.
1687	<i>Newton</i> publishes the "Principia" including the law of universal gravitation.	1837	The London and Birmingham Railway deploy <i>Cooke and Wheatstone's</i> new telegraph signalling and use "railway time" for trains from Euston.
1714	The British Parliament sets a prize of £20,000 for a method for finding <i>longitude</i> at sea.		<i>Charles Dickens</i> mentions railway time in "Dombey and Son".
1724	<i>Jai Singh</i> , Rajah of Jaipur, builds his great sundials in India.	1838	France adopts <i>mean time</i> rather than <i>solar time</i> for civil purposes.
1725	<i>Antoine Thiout</i> (Vesoul, France) designs a clock to show solar time. It is called the equation clock.	1843	<i>Edward Dent</i> (England) patents the <i>dipleidoscope</i> .

Date	Development	Date	Development
1847	<i>Railway time</i> (by then used by most railway companies) is declared “a dangerous innovation” in <i>The Times</i> .	1960	The <i>ephemeris second</i> is set as the basic unit of time.
1848	<i>Sir Charles Wheatstone</i> (1802-1875) invents the <i>polarised light dial</i> .	1972	The <i>equant dial</i> is invented by <i>Fred Sawyer</i> .
1852	Exeter Cathedral clock is put forward 14 minutes to read London Time. There are still many places using local time, e.g. Plymouth and Oxford, plus rural areas.	1974	Robert Gundlach is awarded a US patent for a shadowless sundial; this design has some similarities to the later <i>CD dial</i> .
1862	Léon Foucault measures the distance from the Earth to the Sun.	1977	The Commission des Cadrans Solaires (the French sundial society) is formed as part of the Société Astronomique de France.
1863	Michael Eble is awarded a U.S. patent for his solar horoscope, an <i>altitude dial</i> using an <i>orthographic projection</i> of the sky onto the meridian plane.	1978	The Dutch sundial society “De Zonnewijzerkring” is formed.
1867	Lloyd Mifflin is granted a US patent for an analemma-shaped gnomon to tell mean time.	1981	Boon obtains a US patent for a <i>digital sundial</i> . It is later improved by R L Kellogg.
1872	<i>Mrs Gatty</i> publishes “The Book of Sundials”, giving examples of many dials and their mottoes.	1984	The second is redefined based on atomic rather than Earth-rotation principles, and <i>dynamical time</i> replaces <i>ephemeris time</i> .
1873	Imperial Japan finally gives up the <i>unequal hour</i> system and introduces the European form of timekeeping.	1984	A 1 st century AD Roman <i>cylinder dial</i> , originally excavated in 1884 in Este, N. Italy, is identified.
1880 (Aug)	The Definition of Time Act finally establishes Greenwich time as the basis for civil timekeeping throughout Great Britain.	1989	The British Sundial Society is formed.
1883 (18 Nov)	American railways adopt a four-timezone standard, proposed by Charles F. Dowd (1825-1904) and based on GMT.	1994	The North American Sundial Society is formed.
1884 (Oct)	The International Meridian Conference in Washington, DC, sets the <i>Prime Meridian</i> through Greenwich and defines the standard <i>time zones</i> . It also established the <i>mean solar day</i> , and voiced a desire to extend the use of the decimal system.	1997	The <i>Ptolemaic co-ordinate</i> class of dials is invented by <i>Fred Sawyer</i> .
1892	Major-General John Ryder Oliver is granted British patent No. 1660 for a <i>gnomon</i> shaped to account for the <i>EoT</i> .	1988	The spire of Mont St.Michel (157 metres high) is used to cast a shadow on the surrounding beach to make a sundial around the time of the autumn equinox.
1900	The last French railway stations abandon the use of <i>heliometers</i> for setting their clocks.	1999	The <i>diffraction</i> sundial is invented by M. Catamo and C. Lucarini.
1905	The first time signals are broadcast by the US Naval Observatory, Washington D.C., to specialist radio receivers.	2000	The Japanese Sundial Society is formed.
1906	Gibbs patents his <i>heliometer</i> .		
1911	France finally recognises Greenwich as the origin of <i>longitude</i> (but avoids referring to it as the <i>Prime Meridian</i>).		
1918	America passes legislation legalizing <i>Daylight Saving Time</i> , and the four-timezone system, nationally.		
1922	Hugo Michnik invents the <i>bifilar</i> sundial.		
1924	At the instigation of Astronomer Royal <i>Frank Dyson</i> (1868-1939), the BBC begins the world's first public time broadcast by transmitting the time "pips", having started with a piano playing the Westminster chimes two years earlier.		

APPENDIX I. SIGNS OF THE ZODIAC

Name	Greek name	Ancient date	Sigil	Sign	Season	Mean duration (days)	Sun's longitude on entry	Sun's declination on entry
Aries	κρείος	21 Mar to 19 Apr	a	M	Spring	30.46	0°	0.00°
Taurus	ταῦρος	20 Apr to 20 May	b	N	Spring	30.97	30°	+11.47°
Gemini	δίδυμοι	20 May to 20 Jun	c	O	Spring	31.33	60°	+20.15°
Cancer	καρκίος	21 Jun to 22 Jul	d	P	Summer	31.45	90°	+23.44°
Leo	λέων	23 Jul to 22 Aug	e	Q	Summer	31.29	120°	+20.15°
Virgo	παρθένος	23 Aug to 21 Sep	f	R	Summer	30.90	150°	+11.47°
Libra	ζυγός	22 Sep to 23 Oct	g	S	Autumn	30.39	180°	0.00°
Scorpio	σκορπίος	24 Oct to 21 Nov	h	T	Autumn	29.90	210°	-11.47°
Sagittarius	τοξότης	22 Nov to 21 Dec	i	U	Autumn	29.56	240°	-20.15°
Capricorn	αίγόκερως	22 Dec to 19 Jan	j	V	Winter	29.45	270°	-23.44°
Aquarius	ὑδροχόος	20 Jan to 18 Feb	k	W	Winter	29.59	300°	-20.15°
Pisces	ἰχθύες	19 Feb to 20 Mar	l	X	Winter	29.71	330°	-11.47°

APPENDIX II. ANGLO-SAXON TIDES

Anglo-Saxon name	Approx. modern times (at equinoxes)	Notes
Morgan	4:30am to 7:30am	
Daeg-mael	7:30am to 10:30am	First of the daytime tides
Mid-daeg	10:30am to 1:30pm	noon bisects this tide
Ofanverthr-dagr	1:30pm to 4:30pm	
Mid-aften	4:30pm to 7:30pm	Last of the daytime tides
Onverth-nott	7:30pm to 10:30pm	
Mid-niht	10:30pm to 1:30am	Midnight bisects this tide
Ofanverth-not	1:30am to 4:30 am	

APPENDIX III. ROMAN OCTAVAL SYSTEM

Name	Period
mane	sunrise to end of 3 rd hour
ad meridiem	3 rd to 6 th hour
de meridiem	6 th to 9 th hour
suprema	9 th hour to sunset

APPENDIX IV. CANONICAL HOURS

Name	Latin name	Period
Matins	Mattutinus	midnight to dawn
Lauds		just before daybreak
Prime	Prima	dawn
Terce	Tertia	mid-morning
Sext	Sexta	noon
Nones	Nona	mid-afternoon
Vespers	Vesperus	sunset
Compline	Compieta	sunset to midnight

Note: the prefixes “high” and “low” (“haute” and “basse”, respectively, in Old French) were sometimes attached to these time periods to indicate a time at the beginning or end of the period. The prefix refers to the relative height of the Sun, so high indicates the end of a period before noon (when the Sun is increasing in altitude) but it means the beginning of a period after noon (when the Sun is decreasing in altitude). Hence the term “high noon”, from “haute nones” as the Sun is higher than it is at nones.

APPENDIX V. DOMIFYING LINES

Line	Regiomontanus House	Location on direct south dial
DOM.VII	Libra	Along E horizon line
DOM.VIII	Scorpio	
DOM.IX	Sagittarius	
DOM.X	Capricorn	Along noon line
DOM.XI	Aquarius	
DOM.XII	Pisces	
DOM.I	Aries	Along W horizon line

APPENDIX VI. GREEK AND ROMAN SEASONAL HOURS AND NUMERALS

Modern number	ROMAN			GREEK				
	Symbol	Name of cardinal number	Seasonal hour name	Alphabetical Capital	cur-sive	Name as a letter	Seasonal hour name	Acrophonic number
1	I	unus	prima hora	A	α	alpha	prote	I
2	II	duo	secunda hora	B	β	beta	deutera	II
3	III	tres	tertia hora	Γ	γ	gamma	trite	III
4	III or IV	quattuor	quarta hora	Δ	δ	delta	tetrata	IIII
5	V	quinque	quinta hora	E	ε	epsilon	pempte	Γ
6	VI	sex	sexta hora	F	ξ	digamma	hekta	ΓI
7	VII	septem	septima hora	Z	ζ	zeta	hebdome	ΓII
8	VIII	octo	octava hora	H	η	eta	ogdoe	ΓIII
9	IX	novem	nona hora	Θ	θ	theta	enate	ΓI
10	X	decem	horam decimam	I	ι	iota	dekate	Δ
11	XI	undecim	horam undecimam	IA	ια	iota, alpha	hendekate	ΔI
12	XII	duodecim	horam duodecimam	IB	ιβ	iota, beta	dodekate	ΔII
Other numbers								
13	XIII				ιγ	iota, gamma		ΔIII
14	XIV				ιδ	iota, delta		ΔIIII
15	XV				ιε	iota, epsilon		ΔΓ
16	XVI				ιξ	iota, digamma		ΔΓI
17	XVII				ιζ	iota, zeta		ΔΓII
18	XVIII				ιη	iota, eta		ΔΓIII
19	XIX				ιθ	iota, theta		ΔΓIIII
20	XX				κ	kappa		ΔΔ
30	XXX				λ	lamda		ΔΔΔ
40	XL				μ	mu		ΔΔΔΔ
50	L				ν	nu		ΓΔ
60	LX				ξ	xi		ΓΔ Δ
70	LXX				ο	omicron		ΓΔ ΔΔ
80	LXXX				π	pi		ΓΔ ΔΔΔ
90	XC				ς			ΓΔ ΔΔΔΔ
100	C				ρ	rho		H
200	CC				σ	sigma		HH
300	CCC				τ	tau		HHH
400	CCCC or CD				υ	upsilon		HHHH
500	D				φ	phi		ΓH
600	DC				χ	chi		ΓHH
1000	M				·α			X
2000	MM				·β			XX
3000	MMM				·γ			XXX
10000	Ḳ				·ι			ΓI ΓI

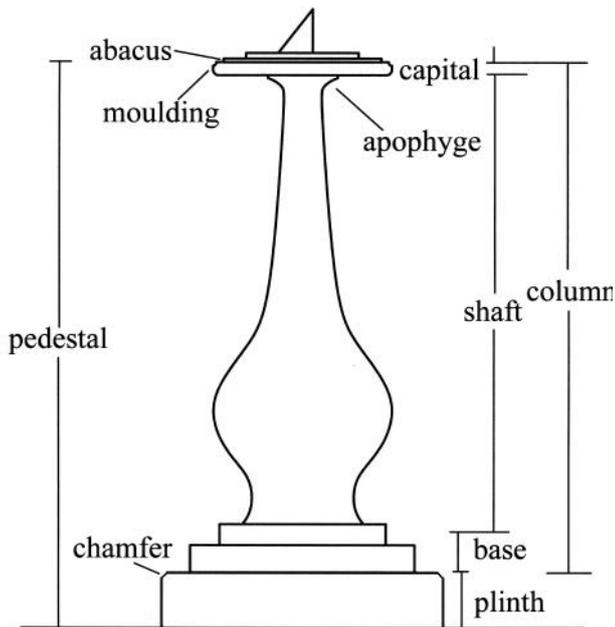
1. Roman numerals K (250) and G (400) are sometimes found.

2. Greek alphabetic numerals are sometimes written with a prime (e.g. α') to distinguish them from letters.

3. The Greek acrophonic multiplier for 5 is sometimes written by enclosing the number in a square.

APPENDIX VII. ARCHITECTURAL AND ECCLESIASTICAL TERMS USED IN DIALLING

The following terms, taken from the field of architecture (Fleming et al) have been adapted to describe architectural features found in dialling. Parts of a church are also included as they are frequently used to describe the location of a dial.



The component parts of a pedestal.

abacus: the flat slab on the top of a *capital*, for example, immediately under a horizontal dial on a *pedestal*.

aisle: the part(s) of a church running alongside the central *nave*. There is often a north and a south aisle, and they are usually of lesser height than the nave.

apophyge: the slight curve at the top and bottom of a *column* where it joins the *capital* or *base*.

apse: large semicircular or polygonal recess, arched or dome-roofed, at the end of a church.

baluster: an architectural term for the short pillars which form the supports for a balustrade. The term can be used in dialling to describe the common variety of *shaft* for a *pedestal* which is bulbous towards the bottom and rises to a neck of smaller diameter, similar to that shown in the figure above.

banded shaft: (or blocked shaft) a *column* broken by plain or rusticated blocks of stone.

base: part of a *pedestal* for a dial, it stands on the *plinth* and supports the *column*.

buttress: a mass of masonry or brickwork projecting from or built against a wall to give additional strength.

capital: the head or crowning feature of a *column*. Many stylised forms exist and have special names.

car-touche: (pron. kar-toosh) a carved tablet or drawing



A stiff-leaved capital.

representing a scroll with rolled up ends, used ornamentally or bearing an inscription, coat of arms etc.

caryatid: strictly, a sculptured female figure used as a *column* to support a dial, etc. It can be used more

loosely for other human figures, e.g. **Atlantes** (male caryatids), **Herms** (three-quarter-length figures), and **Terms** (tapering columns merging at the top into human, animal or mythical figures).

chamfer: the surface made when the sharp edge (**arris**) of a stone block is cut away, usually at an angle of 45° to the other two surfaces. It is called a hollow chamfer when the surface is made concave.

chancel: a part of a church, at its east end and near the altar, reserved for the clergy, choir, etc.

clerestory: part of a wall of a cathedral or large church, with a series of windows above the aisle roof.

column: in classical architecture, it is a part of an *Order*, comprising the *capital*, *shaft* and *base* and is circular or square in cross-section. This definition can also be adopted for dialling purposes.

compound column: a column comprising a number of merged or semi-merged *shafts*.

corbel: a projecting block, usually of stone, inserted into a wall to support, for example, a vertical dial.

crown: a decoration over the top of a vertical dial as an alternative to a *pediment*.

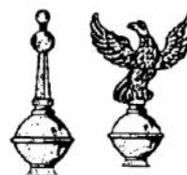
entablature: the upper part of an *Order*, made up of architrave, frieze, cornice etc. Loosely, everything above the *capital*.

finial: a formal pointed ornament on top of a canopy, gable etc. It is sometimes seen on top of a *pillar dial*, often in the form of a ball-and-spire or a fleur-de-lys. On an *obelisk dial*, the finial itself may carry many dial faces.

flute: a semicircular vertical groove in a *pillar*.

foliated: carved with a leaf ornament.

helix: a spiral motif, especially on a *shaft* or *column*.

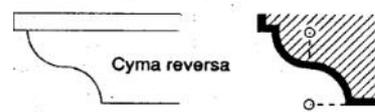
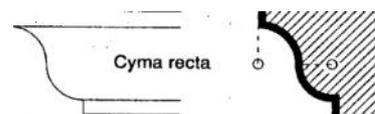


Ball and Eagle finials.

moulding: a continuous ornamental band around a *shaft*, *column*, *capital* etc. There are many specially named types.

nave: the body of a church, especially from the west door to the *chancel* and usually separated from the *aisles* by *pillars*.

obelisk: a tall tapering shaft of stone, usually monolithic with a square or rectangular section ending with a



Ogee and reverse-ogee mouldings.

pyramidal apex. Prominent in Ancient Egypt as a solar symbol, often

at the entrance to tombs or as a cult object in shrines to the sun.

Order: in classical architecture, a term used to describe a column with its *base, shaft, capital* and entablature, designed in one of a number of accepted modes, for example Doric or Ionic. The component descriptions of these Orders have been adapted for dialling purposes.

pedestal: the term adopted by diallists to describe the whole structure, usually of stone, used to support a dial (most usually horizontal). See the figure above.

pediment: a low-pitched gable, sometimes seen over the top of vertical dials. It may be open at the apex, in which case it is termed a **broken-apex** ~ or sometimes just a **broken pediment**. Versions with curved segments are called **swan-neck** ~.

pillar: similar to the classical *column*, but need not have the simple circular or square cross section.



Swan and broken-necked (or broken-top) pediments.



plinth: the bottom part of a *pedestal*, either in direct contact with the ground or with

the general horizontal surface. It is often *chamfered* or

with a *moulding* around it.

Priest's door: a door on the south-side of the *chancel* of a church, used by the clergy. Its surround is a common site for *mass dials*.

quoin: the well-finished stones forming the corners of brick or stone walls, including around windows etc. They are often the site of *mass dials*.

shaft: the trunk of a classical *column*, between the *base* and *capital*. It may be used more loosely in dialling to describe the similar section of a *pedestal*.

solarium: a sun terrace or loggia.

spandrel: an architectural term for the space between the shoulder of an arch and the surrounding rectangular brickwork. In dialling, the term can be used to describe the corner areas of a square *dial plate* with a circular *chapter ring*.

transept: the transverse arms of a cross-shaped church, usually between the *nave* and the *chancel*, but occasionally at the west end of the nave as well

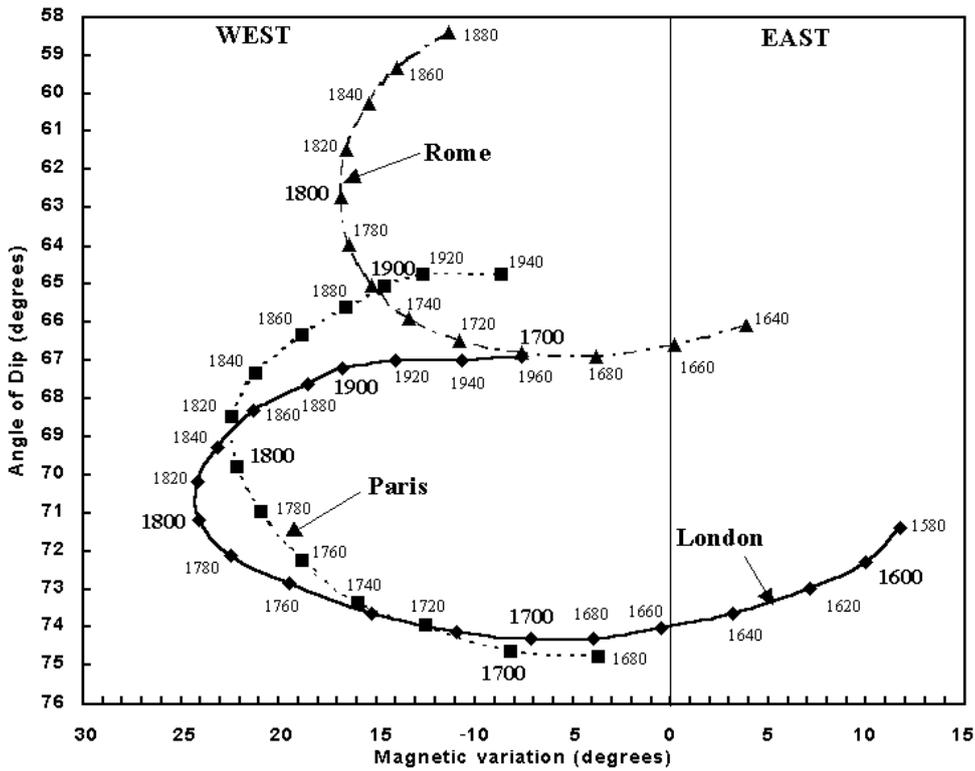
APPENDIX VIII. PLANETARY HOUR SYMBOLS

0Sun [Moon 4Mars 1Mercury 5Jupiter 2Venus 6Saturn

Note that the days are generally named after the master planet for the first hour of the day.

Day	Masters of the Day Planetary hour												Masters of the Night	
	1	2	3	4	5	6	7	8	9	10	11	12		
Sunday	0	2	1	[	6	5	4	0	2	1	[	6	5	1
Monday	[	6	5	4	0	2	1	[	6	5	4	0	2	5
Tuesday	4	0	2	1	[	6	5	4	0	2	1	[	6	2
Wednesday	1	[	6	5	4	0	2	1	[	6	5	4	0	6
Thursday	5	4	0	2	1	[	6	5	4	0	2	1	[	0
Friday	2	1	[	6	5	4	0	2	1	[	6	5	4	[
Saturday	6	5	4	0	2	1	[	6	5	4	0	2	1	4

APPENDIX IX. MAGNETIC VARIATION



The direction of the Earth's magnetic field.

In the UK, the current magnetic variation can be estimated by assuming (in 2000 AD) a value of 2° 37' W on the Greenwich Meridian at 50° N, and then allowing an increase of 15' for each degree of latitude northwards and one of 27' for each degree of longitude westward. The annual change at present is about 12' decrease.

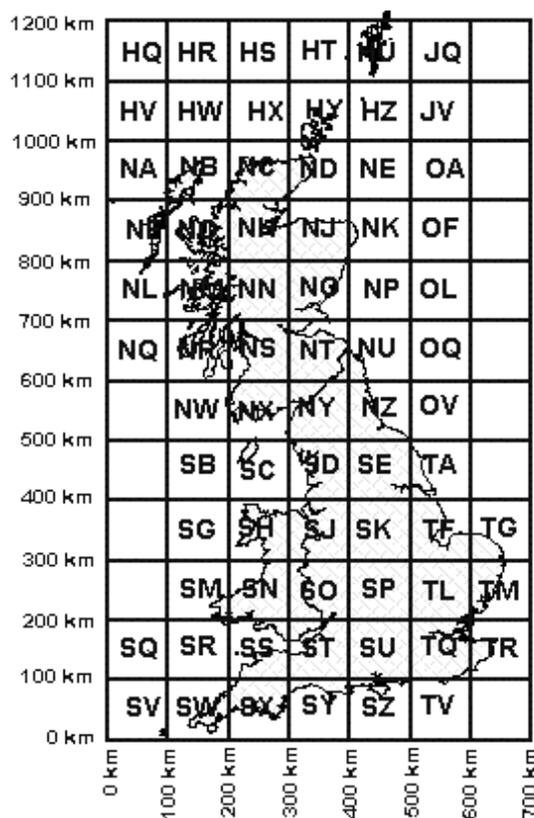
Historical values of the magnetic variation for London (Greenwich from 1900) are given in the following table:

Year	Magnetic variation
1580	11° 15' E
1622	5° 56' E
1665	1° 22' W
1730	13° 00' W
1773	21° 09' W
1850	22° 24' W
1900	16° 29' W
1925	13° 10' W
1950	9° 07' W
1975	6° 39' W
1998	3° 32' W

APPENDIX X. ASTROLABE TERMS

English	Latin	Arabic
alidade	ostensor	al-'Idāda
astrolabe	astrolabium	asturlāb
back	dorsum	zahr
cord		'ilāqa
front, face	facies	wajh
limb	limbus, margo	hajra, tawq, kuffa
mater	mater	umm
pin, axis	clavus, axis	qutb, watad, mihwar
plate	tympanum, tabula regionem	safiha
rete, net, spider	rete, aranea	'ankabût, shabaka
ring	armilla suspensoria	halka
ruler	index (or ostensor)	
shackle		'urwa, habs
swivel pin	armilla reflexea	
throne	armilla fixa	kursī
washer, ring	armilla	fals
wedge, horse, dog	equus, caballus, cuneus	faras

APPENDIX XI. ORDNANCE SURVEY GRID SQUARES



British National Grid 100km squares.

APPENDIX XII. DIALLIST'S CALENDAR

- Notes: 1. Mean declination of the sun at 12:00 UT for the years 2000 to 2049, in decimal degrees.
 2. These dates are not astronomically exact, but are the most probable (Gregorian) dates to be used on dials.

Date	Day no.	Dec ¹ deg	Equation of Time ²	Solar cycle ²	Quarter and cross-quarter days		
					English	USA	Celtic
4 Jan	4	-22.68		Perihelion			
2 Feb	33	-16.71			Candlemas	Groundhog	Imbolic
11 Feb	42	-13.91	maximum				
21 Mar	80	+0.47		Vernal equinox	Spring	Spring	
15 Apr	105	+9.98	zero				
1 May	121	+15.26			May Day		Beltane
13 May	133	+18.53	min (subsidiary)				
4 Jun	155	+22.50		Aphelion			
13 Jun	164	+23.24	zero				
21 Jun	172	+23.43		Summer solstice	Midsummer		
25 Jul	206	+23.36	max (subsidiary)				
1 Aug	213	+17.85			Lammas		Lughnasadh
2 Sep	245	+7.69	zero				
23 Sep	266	-0.31		Autumnal equinox			
1 Nov	305	-14.61	minimum		Hallomas	Halloween	Samhain
11 Nov	315	-17.58			Martinmas		
21 Dec	355	-23.43		Winter solstice			Yule
25 Dec	359	-23.37	zero		Christmas	Christmas	

APPENDIX XIII. EQUATION OF TIME (Mean Values)

<p align="center">Equation of Time (mean) in minutes Equation of time = Mean Local Time - Apparent Local Time.</p> <p align="center">To obtain Mean Local Time add the value given in the table in minutes and decimals to the hour shown by a sundial (Apparent Local Time).</p> <p align="center">Means calculated from the exact values in the years 2000 - 2047 at 12h UT.</p>												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	3.50	13.55	12.31	3.85	-2.89	-2.11	3.93	6.36	-0.01	-10.36	-16.40	-10.93
2	3.97	13.68	12.11	3.56	-3.00	-1.96	4.12	6.29	-0.33	-10.67	-16.42	-10.55
3	4.43	13.79	11.90	3.26	-3.11	-1.79	4.30	6.21	-0.65	-10.99	-16.42	-10.16
4	4.89	13.89	11.69	2.97	-3.20	-1.62	4.48	6.12	-0.98	-11.30	-16.41	-9.76
5	5.34	13.98	11.46	2.69	-3.29	-1.45	4.66	6.03	-1.32	-11.60	-16.39	-9.35
6	5.78	14.05	11.23	2.40	-3.36	-1.27	4.83	5.92	-1.66	-11.90	-16.35	-8.93
7	6.22	14.11	11.00	2.12	-3.43	-1.08	4.99	5.80	-2.00	-12.19	-16.30	-8.50
8	6.64	14.15	10.75	1.84	-3.49	-0.89	5.14	5.67	-2.34	-12.47	-16.24	-8.07
9	7.06	14.19	10.50	1.57	-3.54	-0.69	5.29	5.53	-2.69	-12.74	-16.16	-7.62
10	7.47	14.21	10.25	1.30	-3.57	-0.49	5.43	5.38	-3.04	-13.01	-16.06	-7.17
11	7.87	14.21	9.99	1.04	-3.60	-0.29	5.57	5.22	-3.39	-13.27	-15.95	-6.72
12	8.26	14.21	9.72	0.78	-3.62	-0.09	5.70	5.05	-3.74	-13.52	-15.83	-6.25
13	8.64	14.19	9.45	0.52	-3.63	0.12	5.82	4.87	-4.10	-13.77	-15.70	-5.78
14	9.01	14.16	9.18	0.28	-3.63	0.33	5.93	4.69	-4.45	-14.00	-15.55	-5.31
15	9.36	14.12	8.90	0.03	-3.62	0.55	6.03	4.49	-4.81	-14.23	-15.38	-4.83
16	9.71	14.06	8.61	-0.20	-3.60	0.76	6.13	4.29	-5.17	-14.44	-15.20	-4.34
17	10.04	14.00	8.33	-0.44	-3.57	0.98	6.21	4.08	-5.52	-14.65	-15.01	-3.85
18	10.37	13.92	8.04	-0.66	-3.54	1.20	6.29	3.86	-5.88	-14.85	-14.81	-3.36
19	10.68	13.83	7.75	-0.88	-3.49	1.41	6.36	3.63	-6.24	-15.03	-14.59	-2.87
20	10.98	13.73	7.45	-1.09	-3.43	1.63	6.42	3.39	-6.59	-15.21	-14.35	-2.38
21	11.26	13.62	7.15	-1.29	-3.37	1.85	6.47	3.14	-6.95	-15.37	-14.10	-1.88
22	11.54	13.49	6.86	-1.49	-3.30	2.07	6.51	2.89	-7.30	-15.53	-13.84	-1.38
23	11.80	13.36	6.56	-1.68	-3.21	2.28	6.54	2.63	-7.65	-15.67	-13.57	-0.88
24	12.05	13.22	6.26	-1.86	-3.12	2.50	6.56	2.36	-8.00	-15.80	-13.28	-0.39
25	12.28	13.06	5.95	-2.03	-3.02	2.71	6.57	2.09	-8.35	-15.92	-12.98	0.11
26	12.50	12.90	5.65	-2.19	-2.92	2.92	6.57	1.81	-8.69	-16.03	-12.67	0.60
27	12.71	12.73	5.35	-2.35	-2.80	3.13	6.56	1.52	-9.03	-16.12	-12.35	1.10
28	12.91	12.55	5.05	-2.50	-2.68	3.33	6.54	1.23	-9.37	-16.20	-12.01	1.58
29	13.09		4.75	-2.64	-2.55	3.54	6.51	0.93	-9.70	-16.27	-11.66	2.07
30	13.25		4.45	-2.77	-2.41	3.73	6.47	0.62	-10.03	-16.33	-11.30	2.55
31	13.41		4.15		-2.27		6.42	0.31		-16.37		3.03

The Equation of Time is zero on April 15, June 12, September 1, and December 25.

Note that the above values are average values and hence are shown to hundredths of a minute. The values on any individual date may vary by up to 20 seconds (0.3 minutes) from these figures due to the leap year cycles. Also, the value of EoT will change between sunrise and sunset on a given day by up to 10seconds (in the winter months).

Data courtesy of G. Ferrari.

APPENDIX XIV. SUN'S DECLINATION

Declination of the Sun												
Mean values of the Declination of the Sun in decimal degrees.												
Mean values calculated from the exact values in the years 2000 - 2047 at 12h UT.												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	-22.99	-17.07	-7.45	4.68	15.19	22.10	23.08	17.92	8.14	-3.33	-14.54	-21.85
2	-22.90	-16.78	-7.07	5.07	15.49	22.23	23.00	17.66	7.78	-3.72	-14.86	-22.00
3	-22.81	-16.49	-6.68	5.45	15.78	22.36	22.93	17.40	7.41	-4.10	-15.17	-22.14
4	-22.71	-16.19	-6.30	5.83	16.07	22.47	22.84	17.14	7.04	-4.49	-15.48	-22.28
5	-22.60	-15.89	-5.91	6.21	16.36	22.58	22.75	16.87	6.67	-4.87	-15.78	-22.41
6	-22.48	-15.58	-5.52	6.59	16.64	22.69	22.65	16.59	6.30	-5.26	-16.08	-22.53
7	-22.35	-15.27	-5.14	6.97	16.92	22.78	22.54	16.31	5.93	-5.64	-16.38	-22.64
8	-22.22	-14.95	-4.75	7.34	17.19	22.88	22.43	16.03	5.55	-6.02	-16.67	-22.75
9	-22.08	-14.63	-4.35	7.71	17.45	22.96	22.31	15.74	5.17	-6.40	-16.96	-22.85
10	-21.94	-14.31	-3.96	8.08	17.72	23.04	22.18	15.45	4.79	-6.78	-17.24	-22.94
11	-21.78	-13.98	-3.57	8.45	17.97	23.11	22.05	15.15	4.41	-7.16	-17.52	-23.02
12	-21.62	-13.65	-3.18	8.82	18.23	23.17	21.91	14.85	4.03	-7.53	-17.79	-23.10
13	-21.45	-13.32	-2.78	9.18	18.47	23.23	21.77	14.55	3.65	-7.91	-18.05	-23.17
14	-21.28	-12.98	-2.39	9.54	18.72	23.28	21.62	14.24	3.27	-8.28	-18.31	-23.23
15	-21.10	-12.64	-1.99	9.90	18.95	23.32	21.46	13.93	2.88	-8.65	-18.57	-23.28
16	-20.91	-12.29	-1.60	10.25	19.18	23.36	21.30	13.61	2.50	-9.02	-18.82	-23.33
17	-20.72	-11.94	-1.20	10.60	19.41	23.39	21.13	13.30	2.11	-9.38	-19.07	-23.36
18	-20.52	-11.59	-0.81	10.95	19.63	23.41	20.95	12.97	1.72	-9.75	-19.30	-23.39
19	-20.31	-11.24	-0.41	11.30	19.84	23.42	20.77	12.65	1.34	-10.11	-19.54	-23.42
20	-20.09	-10.88	-0.02	11.64	20.05	23.43	20.59	12.32	0.95	-10.47	-19.77	-23.43
21	-19.87	-10.52	0.38	11.98	20.26	23.44	20.39	11.99	0.56	-10.82	-19.99	-23.44
22	-19.65	-10.15	0.77	12.32	20.46	23.43	20.20	11.65	0.17	-11.18	-20.20	-23.43
23	-19.41	-9.79	1.17	12.65	20.65	23.42	19.99	11.31	-0.22	-11.53	-20.41	-23.42
24	-19.18	-9.42	1.56	12.98	20.83	23.40	19.78	10.97	-0.61	-11.88	-20.61	-23.41
25	-18.93	-9.05	1.95	13.31	21.01	23.37	19.57	10.63	-1.00	-12.22	-20.81	-23.38
26	-18.68	-8.67	2.35	13.63	21.19	23.34	19.35	10.28	-1.39	-12.56	-21.00	-23.35
27	-18.43	-8.30	2.74	13.95	21.36	23.30	19.12	9.93	-1.77	-12.90	-21.19	-23.31
28	-18.16	-7.92	3.13	14.27	21.52	23.26	18.89	9.58	-2.16	-13.24	-21.36	-23.26
29	-17.90		3.52	14.58	21.67	23.20	18.66	9.22	-2.55	-13.57	-21.53	-23.20
30	-17.63		3.91	14.88	21.82	23.14	18.41	8.86	-2.94	-13.90	-21.70	-23.14
31	-17.35		4.30		21.96		18.17	8.50		-14.22		-23.07

The above values are averages and hence are shown to a hundredth of a degree. The value on any particular date may vary by up to around 0.3° (18 arc-minutes) due to the leap-year cycle.

Data kindly supplied by Gianni Ferrari.

APPENDIX XV. SUN'S LONGITUDE

Longitude of the Sun												
Mean values of the Longitude of the Sun in decimal degrees.												
Means calculated from the exact values in the years 2000 - 2047 at 0h UT.												
Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	280.427	311.986	340.520	11.389	40.756	70.647	99.308	128.892	158.697	187.944	218.686	248.905
2	281.446	313.001	341.524	12.376	41.726	71.606	100.262	129.849	159.664	188.928	219.687	249.918
3	282.466	314.015	342.527	13.363	42.697	72.564	101.215	130.806	160.632	189.911	220.688	250.932
4	283.485	315.030	343.530	14.348	43.666	73.521	102.169	131.763	161.601	190.896	221.689	251.946
5	284.504	316.044	344.532	15.334	44.636	74.479	103.122	132.721	162.570	191.881	222.691	252.961
6	285.523	317.058	345.534	16.318	45.604	75.436	104.075	133.678	163.540	192.866	223.694	253.975
7	286.543	318.071	346.535	17.302	46.573	76.393	105.029	134.636	164.510	193.852	224.697	254.991
8	287.562	319.084	347.536	18.286	47.541	77.350	105.982	135.595	165.480	194.839	225.700	256.006
9	288.581	320.097	348.536	19.269	48.508	78.307	106.936	136.553	166.451	195.826	226.704	257.022
10	289.600	321.110	349.535	20.251	49.475	79.263	107.889	137.512	167.423	196.814	227.709	258.038
11	290.619	322.122	350.535	21.233	50.442	80.219	108.843	138.471	168.394	197.802	228.714	259.054
12	291.638	323.133	351.533	22.214	51.408	81.175	109.796	139.431	169.367	198.791	229.719	260.070
13	292.657	324.145	352.531	23.195	52.373	82.131	110.750	140.390	170.340	199.780	230.725	261.087
14	293.676	325.156	353.529	24.175	53.339	83.086	111.704	141.351	171.313	200.770	231.731	262.104
15	294.694	326.166	354.526	25.155	54.303	84.042	112.657	142.311	172.287	201.761	232.738	263.121
16	295.713	327.176	355.522	26.134	55.268	84.997	113.611	143.272	173.262	202.752	233.746	264.138
17	296.731	328.186	356.518	27.112	56.232	85.952	114.565	144.233	174.237	203.744	234.753	265.156
18	297.750	329.195	357.513	28.090	57.195	86.906	115.519	145.194	175.213	204.736	235.761	266.173
19	298.768	330.204	358.508	29.068	58.158	87.861	116.474	146.156	176.189	205.729	236.770	267.191
20	299.786	331.213	359.502	30.044	59.121	88.816	117.428	147.118	177.165	206.722	237.779	268.209
21	300.804	332.221	0.496	31.021	60.084	89.770	118.382	148.081	178.142	207.716	238.789	269.227
22	301.821	333.228	1.489	31.997	61.046	90.724	119.337	149.044	179.120	208.711	239.798	270.246
23	302.839	334.236	2.482	32.972	62.007	91.678	120.292	150.008	180.098	209.706	240.809	271.264
24	303.856	335.242	3.474	33.947	62.969	92.632	121.247	150.971	181.077	210.702	241.819	272.283
25	304.873	336.249	4.465	34.921	63.930	93.586	122.202	151.935	182.057	211.698	242.830	273.301
26	305.890	337.254	5.456	35.895	64.890	94.540	123.157	152.900	183.036	212.695	243.842	274.320
27	306.906	338.260	6.446	36.868	65.851	95.494	124.112	153.865	184.017	213.692	244.854	275.339
28	307.923	339.264	7.436	37.841	66.810	96.448	125.068	154.831	184.998	214.690	245.866	276.358
29	308.939		8.425	38.813	67.770	97.401	126.024	155.796	185.979	215.688	246.878	277.377
30	309.955		9.414	39.785	68.729	98.355	126.980	156.763	186.962	216.687	247.891	278.396
31	310.970		10.402		69.688		127.936	157.730		217.686		279.415

The Longitude of the Sun becomes 0° at the Spring Equinox and has the value $12h = 180^\circ$ at the Autumn Equinox. Its value is a multiple of 30° at the instants in which the sun 'enters' a zodiac sign. The Longitude and Declination of the sun are related by the equation:

where ε is the Ecliptic Obliquity and λ the longitude.

Data kindly supplied by Gianni Ferrari.

APPENDIX XVI. ENGLISH ROYAL PERIODS

Note also:

Stuart 1603-1649 and 1660-1714 (1371-1714 in Scotland)
Hanovarian 1714-1901

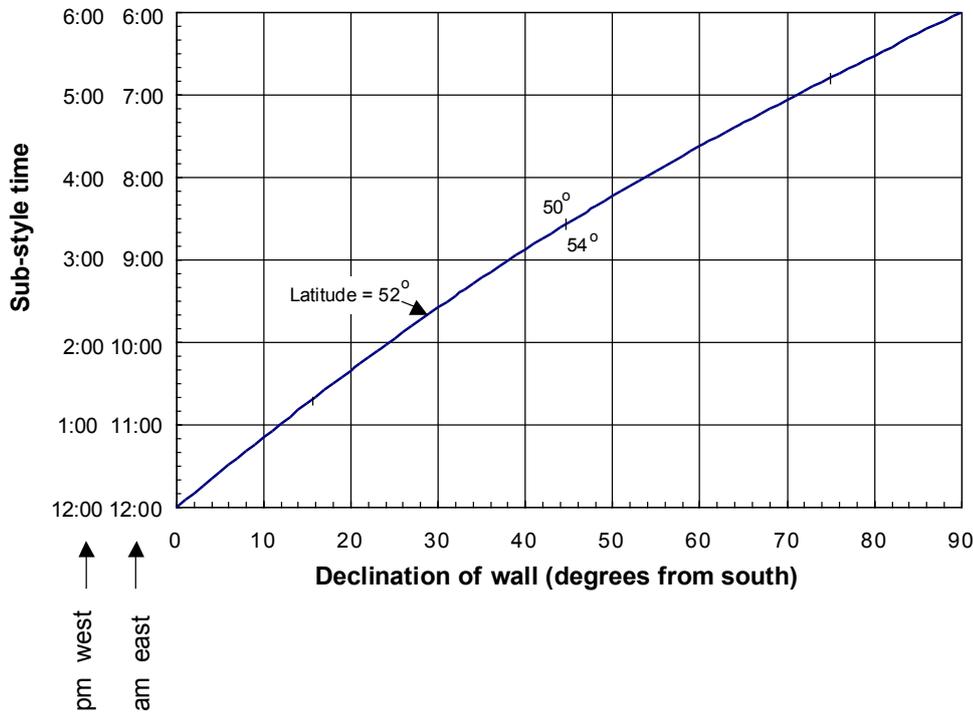
Other periods:

Roman AD 43 to 410
Saxon 410 to 1100
Medieval {mediaeval} 410 to 1485
Dark Ages c.500-1100
Norman 1066 to c.1200
High medieval c.1200-1400
Renaissance c.1300 to 1600

English sundials are sometimes dated according to the monarch(s) reigning at the time. The most usual periods are given below.

Period	Dates	Monarchs
Tudor	1485-1603	Henry VII, Henry VIII, Edward VI, Mary I, Elizabeth I
Elizabethan	1558-1603	Elizabeth I
Jacobean	1603-1625	James I
Commonwealth	1649-1660	None
William & Mary	1689-1702	Mary II, William III
Georgian	1714-1830	George I, George II, George III, George IV
Regency	1811-1820	George III
Victorian	1837-1901	Victoria
Edwardian	1901-1910	Edward VII
Georgian	1910-1952	George V, Edward VIII, George VI

APPENDIX XVII. WALL DECLINATIONS



The graph above shows the position of the sub-style line amongst the hour lines for a vertical dial declining from the south. It is drawn for a latitude of 52° (central and southern Britain) but the small vertical error bars show that there are only small variations across the whole of the UK. The graph assumes that the dial has been correctly designed for Local Apparent Time.

The equation of the curve is:

$$h_{s.style} = \arctan \left\{ \frac{\tan d}{\sin \phi} \right\}$$

where $h_{s.style}$ is the equivalent hour angle of the sub-style time (divide by 15° to obtain decimal hours from noon).

APPENDIX XVIII. DATES OF ADOPTION OF GMT-BASED TIMEZONES

Date	Countries	Date	Countries
1848	Great Britain (legalized in 1880)	1925	Cuba
1879	Sweden	1930	Bermuda
1883	Canada, United States (legalized in 1918)	1931	Paraguay
1884	Serbia	1932	Barbados, Bolivia, Dutch East Indies
1888	Japan	1934	Nicaragua, East Niger
1892	Belgium, Holland, South Africa	1936	Labrador
1893	Italy, Germany, Austria-Hungary (railways)	1937	Caymen Islands, Curacao, Equador, Newfoundland
1894	Bulgaria, Denmark, Norway, Switzerland, Romania, Turkey (railways)	1939	Persia
1895	Australia, New Zealand, Natal	1948	Aden, Bahrein, British Somaliland, Calcutta, Dutch Guiana, Kenya, Federated Malay States, Oman, Uganda, Zanzibar
1896	Formosa	1953	Raratonga, South Georgia
1899	Puerto Rico, Philippines	1954	Cook Islands
1900	Egypt, Alaska	1959	Maldiv Island Republics
1901	Spain	1962	Saudi Arabia
1902	Mozambique, Rhodesia	1972	Liberia
1904	China (coastal), Korea, Manchuria, North Borneo		
1905	Chile		
1906	India (except Calcutta), Ceylon, Seychelles		
1908	Faroe Islands, Iceland		
1911	France, Algeria, Tunis and many French overseas possessions, British West Indies		
1912	Portugal and overseas possessions, Samoa, Hawaii, Midway and Guam. Timor, Jamaica, Bahamas		
1913	British Honduras, Dahomey		
1914	Albania, Brazil, Colombia		
1916	Greece, Ireland, Poland, Turkey (legal)		
1917	Iraq, Palestine		
1918	Guatamala, Panama, Gambia, Gold Coast		
1919	Latvia, Nigeria		
1920	Argentina, Uruguay, Burma, Siam		
1921	Finland, Estonia, Costa Rica		
1922	Mexico		
1924	Java, USSR		

APPENDIX XIX. FORMS OF NUMERALS

Modern	Roman	Arab	Modified Arab	Early Europe
1	I	١	∇	I
2	II	٢	∇	Z
3	III	٣	∇	3
4	III or IV	٤	∇	2
5	V	٥	0	4
6	VI	٦	∇	6
7	VII	٧	∇	∧
8	VIII	٨	∇	8
9	IX	٩	∇	9
10	X	١٠	∇°	IO
11	XI	١١	∇	II
12	XII	١٢	∇	IZ

Notes

1. "Modern" numerals are sometimes called "Arabic" or "Arabic-Hindu" to reflect their origins (although this confuses many readers).

2. "Modified Arab" numerals were used on some clocks and dials from about 1700 to 1850.

3. "Early Europe" means the period from 1200 to 1400, with the form of the numerals gradually changing to the Modern ones. The Z-like 2 persisted the longest, particularly in Germany, disappearing around 1700.

APPENDIX XX. JAPANESE TIME RECKONING BEFORE 1873

Hour	Numeral	Zodiac sign	Animal
6 (sunset)	六	酉	Cock
5	五	戌	Dog
4	四	亥	Boar
9 (midnight)	九	子	Rat
8	八	丑	Bull
7	七	寅	Tiger
6 (sunrise)	六	卯	Hare
5	五	辰	Dragon
4	四	巳	Serpent
9 (noon)	九	午	Horse
8	八	未	Goat
7	七	申	Ape

Notes

The Japanese reckoned their days starting at sunset. The period between sunrise and sunset was divided into six equal parts or "tokis". Their nights were also divided into 6 tokis. Each toki was further divided into 10 buns. Their tokis were originally named after creatures from the Chinese zodiac. These times later acquired numerals. Due to the numerals 1,2 and 3 already being used in temples, they chose the numerals 4 to 9, but these were counted down towards noon and towards midnight. Sunset was therefore 6 tokis, sunrise at 6 tokis and noon at 9 tokis. Due to the varying length of the days at different seasons, it was possible for day and night time tokis to differ as much as 2:1.

From 1873, Japan adopted a standard *equal hour* system.

APPENDIX XXI. CLIMATES

Climate	Parallel	Latitude		Longest day	
		deg	min	hr	min
I	1	2	59	12	15
	2m	6	18	12	30
	3	11	29	12	45
II	4m	15	36	13	0
	5	19	33	13	15
III	6m	23	8	13	30
	7	26	50	13	45
IV	8m	29	49	14	0
	9	32	48	14	15
V	10m	35	35	14	30
	11	38	9	14	45
VI	12m	40	32	15	0
	13	42	41	15	15
VII	14m	44	42	15	30
	15	46	33	15	45
VIII	16m	48	15	16	0
	17	51	14	16	30
IX	18m	53	46	17	0
	19	55	55	17	30
X	20m	57	44	18	0
	21	59	20	18	30
XI	22m	60	39	19	0
	23	61	47	19	30
XII	24m	62	4	20	0
	25	64	12	21	0
XIII	26m	65	10	22	0
	27	65	43	23	0
XIV	28m	65	54	24	0
				Con- tinual days	Con- tinual nights
XV	29	66	2	15	12
	30m	66	53	31	27
XVI	31	67	43	45	41
	32m	69	30	62	58
XVII	33	71	8	77	71
	34m	73	0	98	87
XVIII	35	75	56	108	101
	36m	78	6	124	117
XIX	37	81	10	139	132
	38m	84	0	156	148
XX	39	87	40	172	162
	40m	90	0	188	180

A table of Climates, according to Ricciolus. These are for the northern hemisphere: the figures for the southern hemisphere are the same except the the numbers of continuous days and nights are interchanged. Note that the "middle" latitudes of each climate are central in terms of the length of the longest day, not geographically

APPENDIX XXII. WIND AND COMPASS ROSES

Note: The exact directions of the winds depends on the design location of the dial.

Direction	Latin compass direction	Wind name		
		Latin	Greek	European
SE	Meridies	Eurus	εὔρος	Sirocho
S		Auster	νότος	Ostro
SW		Africus	λίψ	Lebechio
W	Ortus	Faonius, Favonius	ζέφυρος	Ponente
NW		Aquilo	σκίρω	Mastro, Mistra
N	Septentrio	Septentrio	βοσέας	Tramontan
NE		Boreas	καικίας	Greco
E	Occasus	Desolinus	ἀπηνλιώτης	Levante

APPENDIX XXIII. CALLIGRAPHY TERMS USED IN DIALLING

The form of lettering on a dial face is often highly characteristic of the period in which it was made, and sometimes can be attributed to an individual maker or group of makers. Calligraphy has its own complex terminology which is sometimes found in descriptions of dials.

ascender: part of a lower-case letter propagating above the mean line.

copperplate: the form of script originally developed for engraving into copper plates and developed into a flowing, formal style of handwriting. Found on many 18th century English metal dials.

cursive: a style resembling handwriting in which the letters are joined together: flowing rather than formal.

descender: part of a lower-case letter which propagates below the base line.

italic: a sloping form of Roman character (although the term is now also used for lineales). Originally from 15th century Venice.

kern: the part of a character (particularly in type) which overhangs the body of the letter. Hence **kerning** - the act of spacing letters so that the kerns overlap.

ligature: the small link which joins two letters of a logotype. The term is sometimes used for the logotype itself.

lineale (font): a font formally known as sans-serif, in which the characters have no serifs and, generally, the strokes have equal weight.

logotype: characters which represent pairs or triplets of

letters, e.g. # ! etc.

long s: the character ſ used in many 17th to 19th century English documents and also found on dials. It is often used as well as the standard s, as in Highneſs.

majuscules: large lettering, either capitals or uncial, with all letters having the same height.

minuscules: lower case letters, as distinct from capitals or uncials. Alternatively, a small cursive script of the Roman alphabet with ascenders/descenders.

Roman (font): a font in which the characters are characterised by having serifs and, generally, where the strokes have differing weights.

script: a font based on cursive characters.

serif: a small stroke or tick-mark finishing off the cross-stroke of a character.

short-ranging figures: numerals which range on the base line, i.e. not the 3, 5, 7, 9 used in early fonts.

swashed: an ornamental letter, usually a capital with an elaborate flourish.

uncial: majuscule characters with rounded, unjoined letters, mainly from 4th to 8th century Europe. A precursor to capital letters.

APPENDIX XXIV - Adoption dates for the Gregorian calendar.

Year	Date	Countries
1582	4 October	Italy, Spain, Portugal, France, Poland
1583		Holland, Flanders, German Catholic states
1700		German & Dutch Protestant states, Denmark
1752	2 September	Britain (and Dominions),
1753		Sweden
1873		Japan
1912		China, Albania
1916		Bulgaria
1918		Russia
1924	Rumania, Greece	
1927		Turkey

Note: For dates before 1700, there was a loss of 10 days. From 1700 onwards, the loss was 11 days. Other calendar changes often accompanied the adoption of the Gregorian calendar.

APPENDIX XXV – ALTITUDES

Term	shadow length	altitude (degrees)
equalis	1	45.0
dupla	2	26.6
tripla	3	18.4
quadrupla	4	14.0
quintrupla	5	11.3
sextrupla	6	9.5

These terms for the sun's altitude are sometimes found on old dials and are based on the length of the shadow of a vertical gnomon. The altitude, a , can be calculated from

$$a = \tan^{-1}(1/L)$$

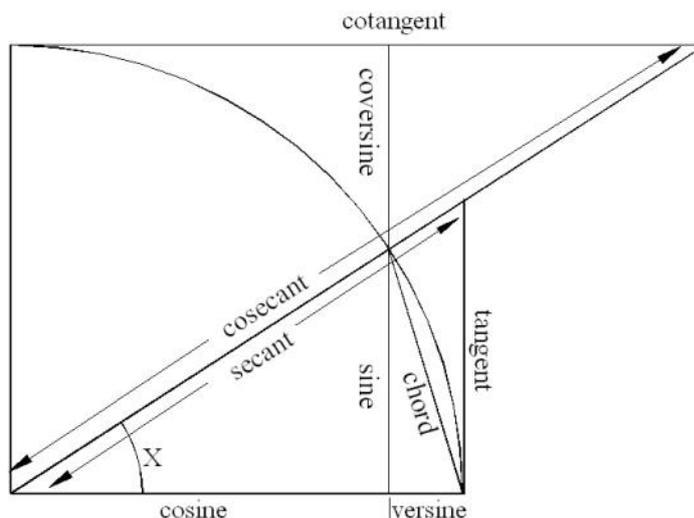
where L is the length of the shadow expressed as a multiple of the gnomon height.

APPENDIX XXVII - ASPECTS

Term	Angle (degrees)
conjunction	0
sextile (sestile)	60
quartile (square)	90
trine	120
opposition	180

These terms are used by astrologers to indicate the angular separation (in celestial longitude) of one celestial body from another.

APPENDIX XXVII - GEOMETRIC DEPICTION OF TRIGONOMETRIC FUNCTIONS



The above geometric representation of the trigonometric functions is based on a circle of unit radius. The functions are often depicted as lengths on old rules and scales.

APPENDIX XXVIII – TERMS USED FOR IMITATION DIALS

The terms listed below for dials which imitate an earlier style or an individual dial are based on the definitions made by Prof. Gerard Turner [G L'E Turner: 'An inquiry into the imitation of scientific instruments' Proc. Sci. Insts: Originals & Imitations. Mus. Boerhaave, Leiden, pp.48-60 (1999)]. They were reproduced, with illustrations, in *BSS Bulletin*, 15(iii), (September 2003).

All imitations should be clearly marked with the name of their maker and the year if they are not to be regarded as forgeries.

Original: A dial whose genuineness is well authenticated.

Imitation: A generic term for all non-original dials.

Reproduction: A dial made in the general style of an earlier period.

Reconstruction: A dial for which there has never been a three-dimensional original (or where the original is known to have been destroyed*): it has been made after a verbal or illustrated description.

Copy: An imitation of an particular, single, antique dial.

Replica*: A copy made by a method (such as a mould drawn from the original or laser 3-D scanning) which ensures an exact replication of the appearance and dimensions of the original.

Facsimile: A look-alike which closely resembles an original but is not made of the same materials (and may be to a different scale*).

Restoration: An amalgam of original parts and modern, replacement, parts.

Forgery: A false dial (including a false signature or date added to an antique item) made with the intention that it should be accepted as genuine, to the prejudice of another person.

Fake*: A colloquial term for a forgery.

* Note: this term or addition to the definition is not in Turner's list.

APPENDIX XXIX INTERNATIONAL TIME ZONES

Time Zone (Hours)	Central Meridian	Name	Places
-11	165° W		Midway, Samoa
-10	150° W		Hawaii, Society Is.
-9	135° W		Alaska, Pitcairn Is.
-8	120° W	Pacific Standard	Whitehorse, Seattle, Los Angeles
-7	105° W	Mountain	Yellow Knife, Denver, Phoenix
-6	90° W	Central Standard	Churchill, Chicago, New Orleans
-5	75° W	Eastern Standard	Montreal, New York, Columbia, Peru
-4	60° W	Atlantic	Nova Scotia, Venezuela, Newfoundland (-30m)
-3	45° W		Greenland, E.Brazil, Argentina
-2	30° W		S.Sandwich Is.
-1	15° W		Cape Verdes Is., Azores
0	0°	Greenwich Mean Time	Great Britain, Iceland, W.Africa
1	15° E	Central European	Mainland Europe, Scandinavia, C.Africa
2	30° E	Eastern European	E.Europe, Middle East, E.C.Africa
3	45° E		Moscow
4	60° E		Gorki, Oman, Mauritius
5	75° E		Pakistan, India (+30m)
6	90° E		Bangladesh, Burma
7	105° E		S.E.Asia, Sumatra
8	120° E		China, Philipines, W.Australia
9	135° E		Korea, Japan, C. Australia (+30m)
10	150° E		Papua New Guinea, Guam, E.Australia
11	165° E		Sakhalin Peninsula, Solomon Is.
12	180° E		New Zealand, Wake, Marshall Is.

SOURCES

SOURCES:

- J. E. Barnet: *Time's Pendulum - the quest to capture time from Sundials to atomic clocks*. Plenum Press, New York, 1998
BSS Bulletin 1989 to 1999
F. Coe, private communication
C. St.J. Daniel: *Sundials*. Shire Publications, Princes Risborough
P. Duffett-Smith: *Easy PC Astronomy*. Cambridge University Press, Cambridge, 1997.
D.E. Duncan: *The Calendar*. Fourth Estate, London, 1998.
J.C. Eade: *The Forgotten Sky – a guide to astrology in English Literature*. Clarendon Press, 1984.
J. Fleming, H. Honour & N. Pevsner: *Architecture and Landscape Architecture*, Penguin, 1998.
M Folkard and J. Ward: *Sundials Australia (second edition)*. Sundials Australia, Adelaide, 1996.
S.L. Gibbs: *Greek and Roman Sundials*. Yale University Press, New Haven, 1976.
B. Hallemands and B. Bunch: *The Timetables of Science*. Simon and Schuster, New York, 1988.
A. P. Herbert: *Sundials - Old and New*. Smoetvhuyn, 1967.
H. Higton: *Sundials - an illustrated history of portable dials*. Philip Wilson Publishers, London, 2001.
M. Hoskin (ed.): *Cambridge Illustrated Astronomy*. Cambridge University Press, Cambridge, 1997.
L. Jardine: *Ingenious Pursuits – building the scientific revolution*. Little, Brown & Co., 1999.
J. B. Kaler: *The Ever-Changing Sky - a guide to the celestial sphere*. Cambridge University Press (Cambridge), 1996.
K. Lippincott: *The Story of Time*. Merrell Holberton, London, 1999.
R. N. Mayall & M. W. Mayall: *Sundials – their construction and use*. Sky Publishing, Cambridge (Mass.), 1994.
J. Meeus: *Astronomical Algorithms*. (2nd edition). Willmann-Bell, Richmond, 1998.
H.R. Mills: *Practical Astronomy*. Albion, Chichester, 1994.
NASS Compendium 1994 to 1999.
National Maritime Museum: *The Planispheric Astrolabe*. Her Majesty's Stationery Office, London, 1976.
C.T. Onions (Ed.): *The Shorter Oxford English Dictionary on Historical Principles*. 3rd edition. Oxford University Press, London, 1968.
R. Porter (ed.): *Dictionary of Scientific Biography*. Hutchinson, Oxford, 1994.
A. L. Rawlings: *The Science of Clocks and Watches*. Longman Group, Bridgend, 1993.
R. R. Rohr: *Sundials – history, theory and practice*. Dover, New York, 1970.
S. Straus: *The Sisesaurus*. Kodansha International, New York, 1995.
G. L'E. Turner: *Scientific Instruments 1500-1900 – an introduction*. University of California Press, Berkeley, 1998
A. E. Waugh: *Sundials – their theory and construction*. Dover, New York, 1973.

Sundial Societies

Other Sundial Societies

Austria - *Arbeitsgruppe Sonnenuhren* - (Gnomonicae Societas Austriaca)

Am Tigls 76A, A-6073 Sistrans/Tyrol, Austria

Belgium - *Zonnewijzerkring Vlaanderen*

Oeverstraat 12, B-9150 Rupelmonde, Belgium

Catalonia, Spain - *Societat Catalana de Gnomonica*

Centre d'Estudis del Rellotge de Sol, Atenes 3, 08006 Barcelona, Catalunya, Spain.

France - *Commission des cadrans solaires of the Societé Astronomique de France*

3, rue Beethoven, 75016 Paris, France

Hungary -

Contact details not known

Italy - *Guppo Milanese Quadranti Solari* - (GQMS)

Japan

Contact details not known

Netherlands - *De Zonnenwijzerkring*

van Gorkumlaan 39, 5641 WN Eindhoven, Netherlands

North America - *North American Sundial Society (NASS)*

8 Sagem Drive, Glastonbury, CT 06033 USA

Quebec - *Commission des cadrans solaires du Quebec*

42 av. de la Brunante, Outremont (Montreal), Quebec H3T 1R4 Canada

Spain - *Asociacion Española de Amigos del los Relojes de Sol*

M. Lombardero, Isaac Peral 48, 28040 Madrid, Spain

Switzerland - *Sonnenuhrenfreunde der Region Basel (SFB)*

F. Muhlemann, Lebernring 4, CH-4107 Ettingen, Switzerland

The British Sundial Society

Patron: The Hon Sir Mark Lennox-Boyd
President: Christopher St J H Daniel MBE
Chairman: Dr Frank King

The Society was formed in 1989 and is a thriving and friendly society of around 400 members.
Our object is to advance the education of the public in the art and science of gnomonics.
We organise meetings and conferences and publish four 48-page journals each year.

For more information, visit www.sundialsoc.org.uk
If you have any query about sundials, send an email to HelpAndAdvice@sundialsoc.org.uk