CUBIC Shadows

How to make a CUBIC sun dial for the common latitudes of the planet earth. The cube dial pictured above is latitude specific. This book shows how to use one set of dial plates for any latitude. However, using the DeltaCAD macros, latitude specific dial plates are easily built.

Simon Wheaton-Smith
October 2012

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NOTE
Please also check SIMPLE SHADOWS, it has some additional material that is not in the booklet.

FREE Please download:
cubicShadows.xls for Excel

from: www.illustratingshadows.com

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INTRODUCTION

There are a number of books on sundials, some easier to find, some harder. From a personally biased perspective, ILLUSTRATING TIME'S SHADOW is by far the best!.

I had grown up with a few sundials, and a lot of clocks. I collected clocks, and when I was a teenager I was given a portable sundial, and later I acquired some astrolabes. The house I was born in was Pilton Manor in Somerset, England. We had one sundial I had a picture of, but I was too small to be able to read it. Then in 1951 we moved to Hey Farm in Somerset also, an old house in much need of repair. In the east end of the lawn there was an old sundial. It was missing some pieces, yet together with its moss and the occasional present from a visiting bird, it was a feature of our life, and a center piece when we used to have tea or picnics on the lawn.


Pilton's sundial


Hey Farm's sundial

I built a number of sundials, some worked better than others and I found what did and did not work. In reading the books I was somewhat frustrated by geometric projections that were not always clear and took a long time to comprehend, some seemed to have some non sequiturs, and the diagrams were not on the same page as the text making it harder still. Some even used different symbols than their associated descriptive text. Some books even appeared to be inconsistent. One book would be great at this feature, poor at another, thus I started to collect charts, tables, and methods.

The objective of this book is to show clearly some methods for making the horizontal sun dial for all sorts of places. Enjoy your trip to a world of sunlight.

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A QUICK HANDS ON PROJECT
BUILD IT FIRST – FIX IT NEXT

The next two pages offer a simple "go ahead and build it" horizontal sundial, then see what needs to be done to make it accurate. The rest of the book is the other way around, theory to understand what is going on, then build it. These two pages help you build a horizontal dial and for all readers, this is a good prelude to the rest of the book. And now, some questions…

1. What is your latitude (how far north or south are you from the equator). Many maps show this, and so does a GPS. In the appendices, Table A2.5 may help.

my latitude is:	

2. **EITHER** download the spreadsheet at:

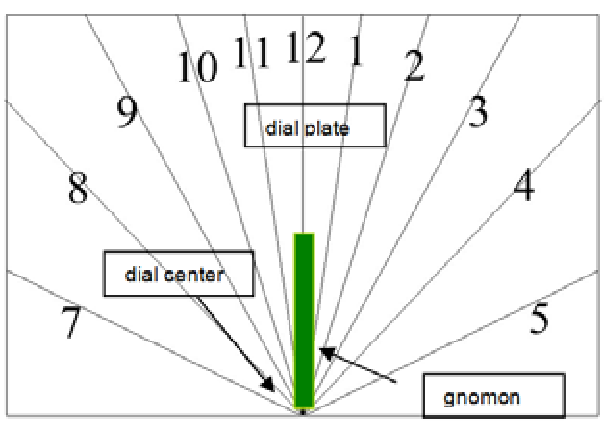
   www.illustratingshadows.com/microShadows.xls

   then enter the latitude. **OR** go to tables A3.1a, A3.1b, or A3.1c in the appendices, look at the latitude at the top of the columns, then find the angles for the hours you wish marked.

6am	6pm	hour line angle	_ _ _ _ _ _ _ _
7am	5pm	hour line angle	_ _ _ _ _ _ _ _
8am	4pm	hour line angle	_ _ _ _ _ _ _ _
9am	3pm	hour line angle	_ _ _ _ _ _ _ _
10am	2pm	hour line angle	_ _ _ _ _ _ _ _
11am	1pm	hour line angle	_ _ _ _ _ _ _ _
noon		hour line angle	_ _ _ _ _ _ _ _

3. Mark the lines on the template "A DRAFTING SHEET FOR HORIZONTAL DIALS" from the appendices. The end result should look roughly like the fan of lines below.

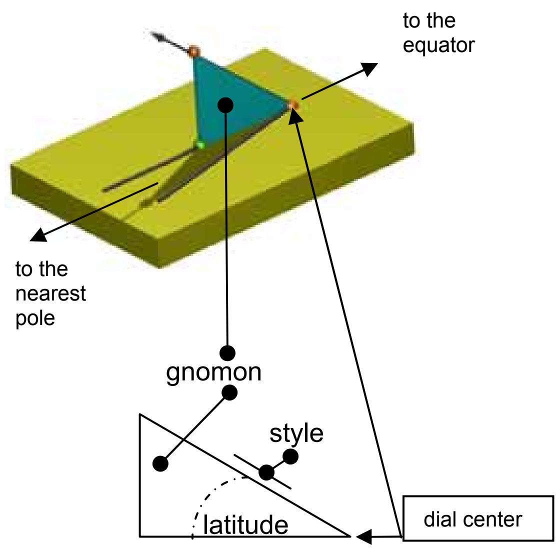
   Noon is going to be on the north south line and the 6am and 6pm lines will be at 90 degrees to that, The other lines will fan out, and their angles depend on your latitude.



Transpose the hour lines to wood, PVC, copper, glass, concrete, or any other medium. This is called the dial plate.

Build a shadow casting device, called a gnomon, it is a triangle whose angle from the dial plate is equal to the latitude. The angle is important, the length is not, unless you want to add other information related to the time of year, discussed in the main part of the book. **NOTE:** the gnomon should be thin. If it is thick as shown above, then the am and

Affix the gnomon to the dial plate, the latitude angle end rests on top of where the hour lines converge (dial center), and it lies on the north south line, or the noon line.



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6. Affix the gnomon to the dial plate, the latitude angle end rests on top of where the hour lines converge (dial center), and it lies on the north south line, or the noon line.

7. Take the dial plate, it's affixed gnomon on the noon line and place it in the sun.

8. Align the noon line with north/south, and the gnomon's end placed on dial center (where it meets the hour lines), should point to the equator, south in the northern hemisphere or north in the southern hemisphere.

   By north, true north is meant, not the north where a compass points. To find true north, first find magnetic north by using a compass but keep away from metal.

Then find your location's magnetic variation, or declination as sun dial people call it. If it is an easterly declination you must back away from north to the west. If it is a westerly declination, you must back away from north to the east. Magnetic declinations are often found on maps, and a table and a map in the appendix has declination information.

my magnetic declination:	E W

Table A2.5 and the maps in appendix 2 mayhelp, and many websites also, you may try:

http://www.magnetic-declination.com/

9. With the dial plate level, the angled part of the gnomon pointing north south, the dial will now read sun-time, or local-apparent-time or LAT for short. It is still not clock accurate. There are **two corrections** to make. One is to correct for your distance from your time zone's reference **longitude**, the other is for the fact the sun is predictably slow or fast (compared to man made watches) as the year progresses, this correction is called the **equation of time or EOT for short**.

10. Find your **longitude**, it is on your GPS unit, or on a map of your area. Aviation and geological survey maps work, but road maps may not. Once you know your longitude, and your time zone, find your time zone's reference longitude.

my longitude is:	

Table A2.5 in the appendices may help.

my time zone reference is:	

Table A2.6 in the appendices may help.

difference between the two is:	

times 4 is:	_ _ _ _ minutes

If your longitude is larger than the reference longitude, then ADD the difference times 4, this is the minutes to add to correct for your location.

If your longitude is smaller than the reference longitude, then SUBTRACT the difference times 4, this is the minutes to add to correct for your location.

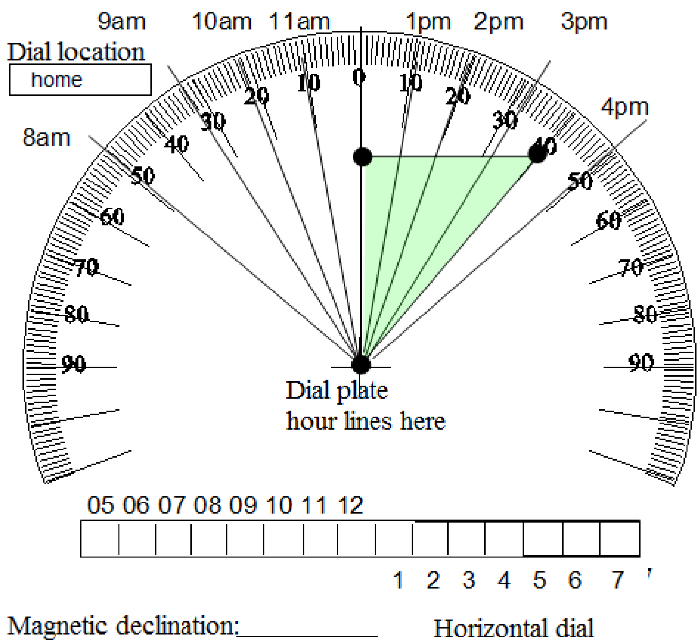
plus [ ] or minus [ ] _ _ _ minutes to correct for location.

11. We now have a dial built for your latitude, aligned north/south, and corrected for your location's distance from the time zone's reference longitude. However it may still be off by plus or minus up to 16 minutes due to the fact the sun's orbit around the earth varies as the year progresses, and the sun similarly moves north or south of the equator. There is a table of corrections for this **equation of time or EOT**, table A2.1 is by the day.

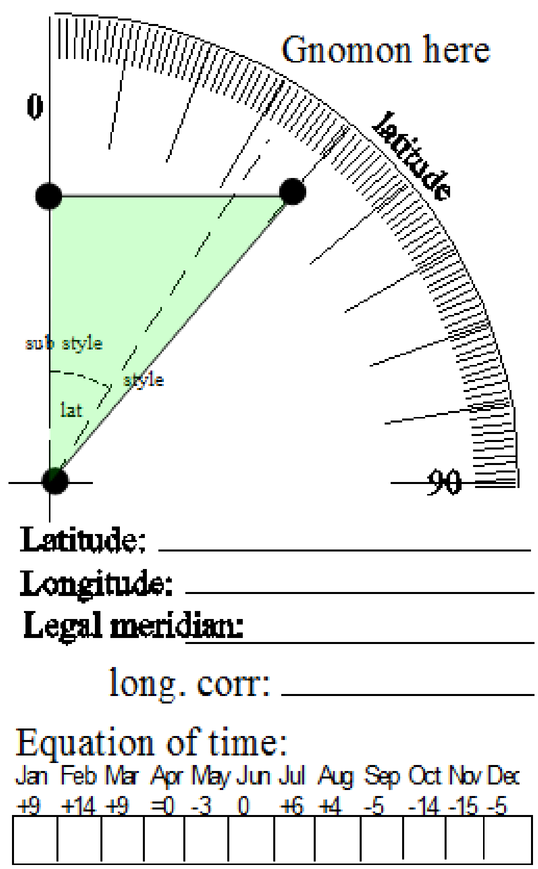
12. That is it! You now have a working horizontal sun dial. To delve into it more, read on....

HORIZONTAL DIAL: Method: Using Tables and protractor

Protractor for the hour lines...



Protractor for the gnomon...



Appendix 3 table A3.1b for latitude 40 provides the following hour line angles assuming no longitude correction.

8am and 4pm	48.07 degrees
9am and 3pm	32.73 degrees
10am and 2pm	20.36 degrees
11am and 1pm	9.77 degrees etc

The hour lines before and after noon are drawn. The gnomon is drawn and moved to dial center. The longitude correction of 4 degrees (at 4 minutes per degree) is 16 minutes, and is west of longitude 105 thus we must add the time. The longitude correction of 16 minutes is added to the equation of time, producing:-

Jan	Feb	Mar	Apr	May	Jun	Jly	Aug
	Sep	Oct	Nov	Dec			
+25	+30	+25	+16	+13	+16	+22	+20
	+11	+2	+1	+11			

The dial plate is aligned to true north, and the shadow is mentally corrected with the revised equation of time (EOT).

Alternatively the hour lines could be adjusted individually for longitude, however the dial would no longer be portable. If the hour lines were longitude adjusted, they would simple be rotated, but by an angle calculated for a time corrected by the 16 minutes, one hour line at a time. The equinox line is derived by extending the gnomon from the nodus to the sub-style line extended, and perpendicular to the style. Longitude corrections of 4 or more degrees cause the resulting combined EOT table to always have the same sign. That is because 4 degrees is 16 minutes, the maximum EOT deviation. This paper dial can be tested in the sun before the final dial is built as is shown in the inset.

THE EVOLUTION OF THE DIAL

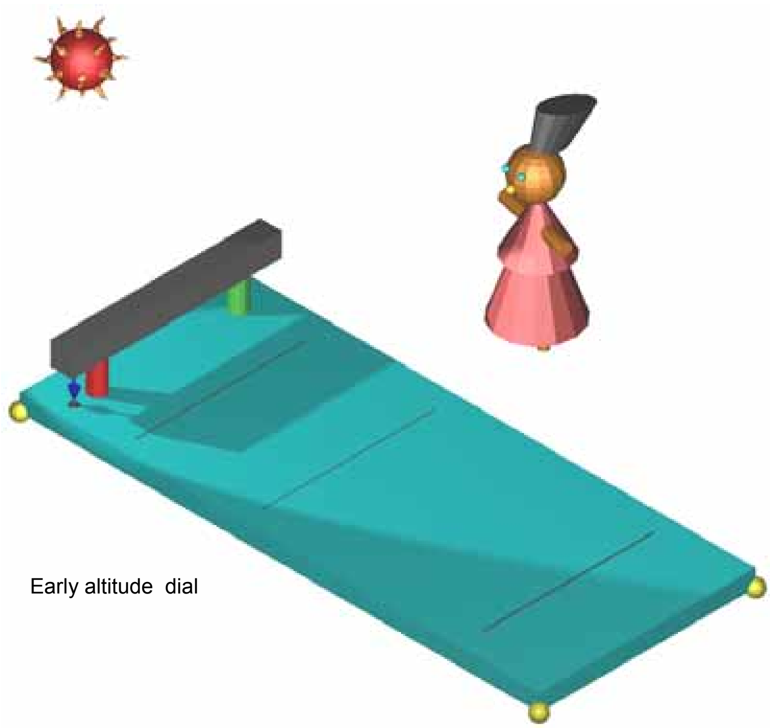
USEFUL DEFINITIONS –

- The **EOT**, or **equation of time** is the difference between the real apparent sun and a virtual perfectly on-time sun that matches the modern "accurate" clock
- Altitude – how high above the horizon the sun is, measured in degrees.
- Azimuth ~ how far east or west of the north-south line the sun is, measured in degrees.

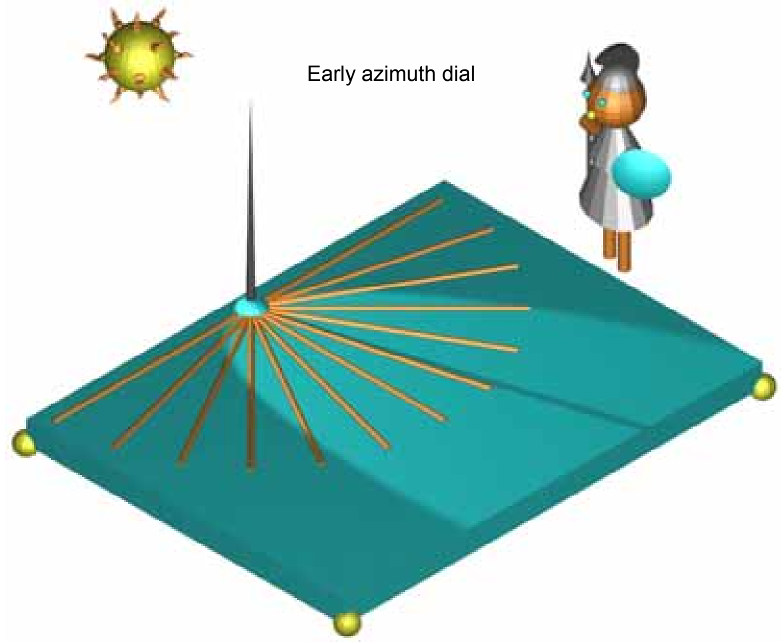
Since the earliest days of the human race, it was important to know when to plant, when to hunt, and a calendar was needed and developed. The sun's angle in the sky compared to the horizon, is its altitude, and early Egyptians employed such dials.

The sun woke up and climbed, ran out of energy in mid day, and becoming tired, descended into the arms of Morpheus. The early Egyptians built a simple dial that could be turned toward the sun, and its angle at mid day cast a shadow of decreasing length as the climate became warmer. Alignment with true north or south was not needed for these altitude measuring dials, since the reference was the sun, and the horizon.

For all altitude dials, north south alignment is not used but the date must be known if the one is to tell the time.



Early altitude dial



As time became more important than the calendar, early Greeks, Arabs, and Romans had business to conduct. And so developed a sundial that measured the azimuth of the sun, its angle compared with true north or south. Such early dials often divided daylight into pieces, yet those pieces were not always of equal duration, sometimes they were just arbitrary divisions. Azimuth dials do not required a gnomon of a calculated height. The line of the shadow aligns with hour lines, or points to hour points.

Of course time, altitude, and azimuth are all somewhat related. And a definitive study of dial history may not show such a sequenced development because different areas of the world evolved differently. As the horse and carriage produced rapid transportation, people needed common time keeping, and equal hours. So was ushered in the perfected sundial. That perfected dial used the angle the sun makes as it appears to orbit around the earth's north-south polar axis.

The reader may have noticed that the sun runs slow or fast depending on the day of the year.

Sun dials use the solar position as the basis for date and for time. The earth orbits the sun, however not by an exact number of days, and even those days vary in an annual cycle. So even city slicker watches are not synchronized as well as we might think. Is the synchronization with the daily rotation of the earth, the annual rotation around the sun, or with the fixed stars?

HOW THE EARTH AND SUN DO THEIR THING

The earth is a planet and from history we know it orbits the sun. Back in medieval times the sun rotated around the earth. Galileo and others nearly got burned at the stake when they said it was the other way round, however it is pretty much accepted that the earth moves around the sun, and by the way, the earth is no longer flat either, it is a sphere in space.

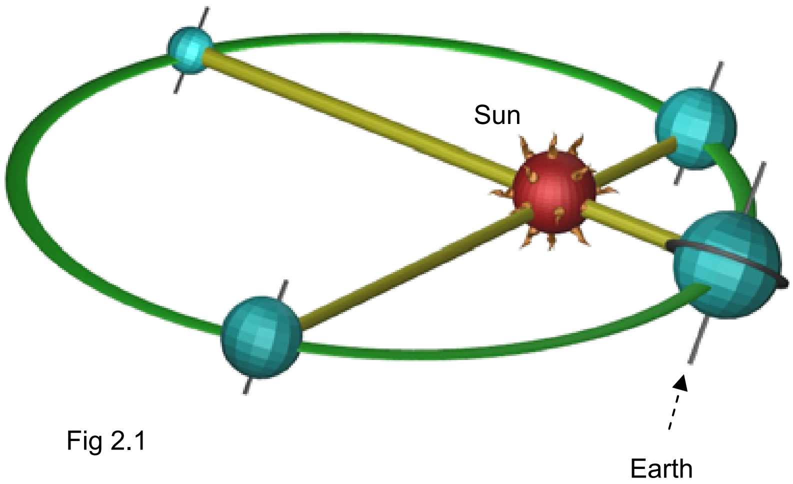


Fig 2.1

The polar axis is what the earth's surface spins around, or in essence, around which the sun apparently rotates. And we call the line running around the middle of the earth, the equator, which is perpendicular to the polar axis.

The blue thing we live on is planet earth, and what is more it is tilted. That is why the seasons vary, and it has a polar axis, and an equator which is at 90 degrees to that axis. The axis is what the earth's surface spins around. That axis is tiled about 23.5° and, looking at figure 2.2, when the sun is below the equator (bottom left in the figure below), the southern hemisphere enjoys summer, and when the sun above the equator (top right in the figure below), winter prevails down under, and summer returns to the northern hemisphere. The earth orbits the sun in an ellipse called the ecliptic, and that together with the earth's tilt, is why day length varies, and why the sun's hours vary somewhat, and hence why the equation of time was developed which corrects the sun for being slow or fast when compared to the watches and clocks. The ecliptic is 23.5 degrees off from the earth's equator.

The pictorial below shows the earth spinning on its axis, and the sun in four different positions.

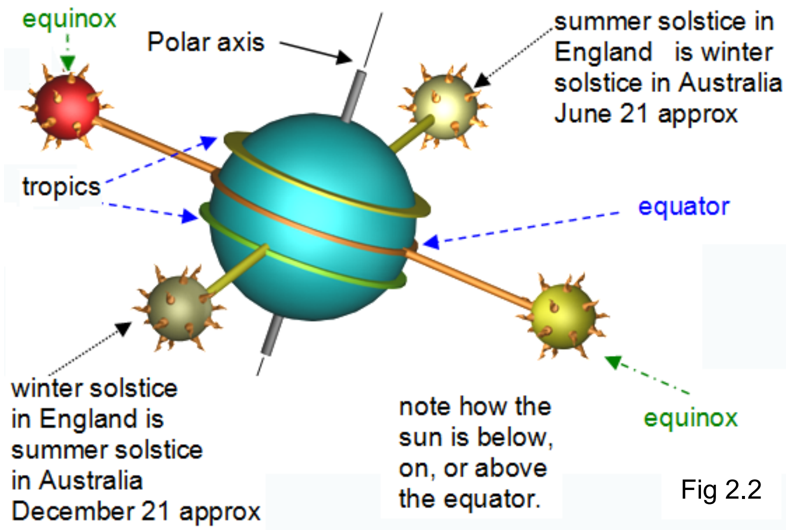


Fig 2.2

While the Earth rotates around the sun, to a sundial it is as if the sun goes around the Earth's polar axis. So for simplicity, we will assume it is before the days Galileo. When the sun is over the equator, top left and bottom right in the picture above, it is the equinox, and the days are equal to the nights in duration, late March and September. By the way, every day on the equator is an equinox, their days are always the same length as their nights. When the sun is over the tropics, i.e. latitude plus or minus 23.44 degrees, it is the solstices, late June and December.

Now let us define a few things that are needed in order to understand location on planet earth. The pole around which the earth spins is tilted by about 23.5° and perpendicular to it is the plane called the equator, see figure 2.3.

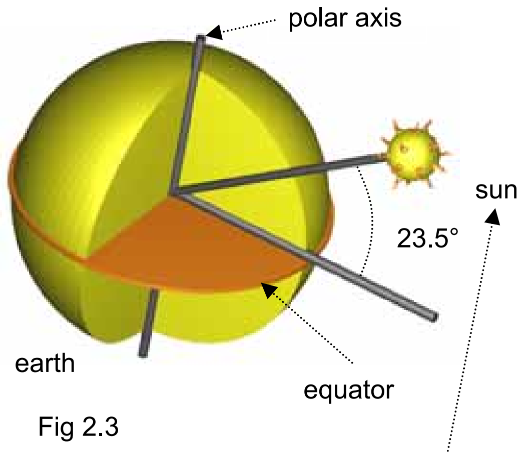


Fig 2.3

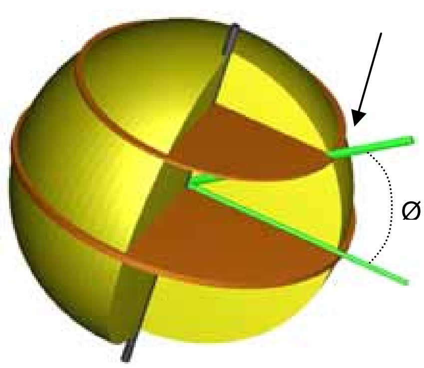
By the way, if the earth looks bigger than the sun, it is because the sun looks small to us here on planet earth, and the earth looks big to us.

Referring to figure 2.4, as a convenience, the earth is sliced up into sections parallel to the equator, and those slices are measured by their angle to the center of the earth. Those angles are called latitude and Ø is its common symbol.

The latitude tells you how far north or south of the equator you are. It is measured in degrees, the equator's latitude is 0° while the north pole is 90°, and one degree of latitude is about 60 nautical miles on the surface, that is how nautical miles came into being.

But how do you know where you are left or right on the planet. The equator is an obvious slice for latitude references, as it is 90° to the polar axis, but there is no such obvious place for the left-right position, so England graciously agreed to defined Greenwich as the reference point.

Fig 2.4 latitude



Referring to figure 2.5, longitude tells how far you are east or west of Greenwich England. However as you go further north or south of the equator, the distance between one longitude degree varies. Whereas a degree of latitude is 60 nautical miles anywhere, for longitude the distance gets smaller as you travel north or south of the equator.

Longitude does have one fixed distance relationship, however, one degree of longitude always accounts for 4 minutes of time in the motion of the sun.

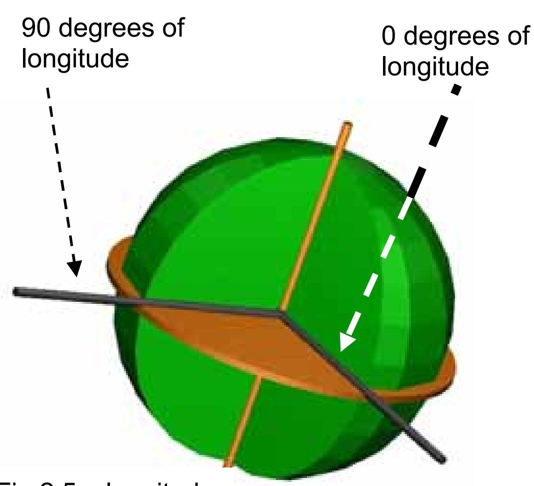
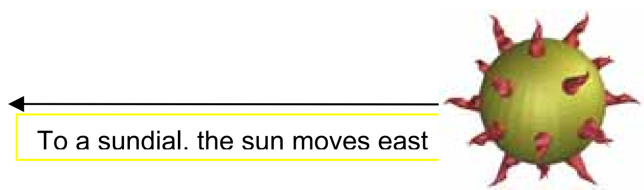


Fig 2.5 longitude

Positions on the planet are identified by latitude (north or south of the equator), and by longitude (east or west of Greenwich England). Because the earth rotates on its axis, some places see the sun later and some earlier. As there are 24 hours in a day, and there are 360 degrees of longitude, 15 degrees equates to one hour, so standard longitudes are established every 15 degrees, but for political reasons they may zigzag around the place. Those longitudes in essence define legal standard time.

Those 15 degrees are split in half for those legal time zones, thus Greenwich is 0° of longitude, and 7.5° west to 7.5° east marks the legal time zone.



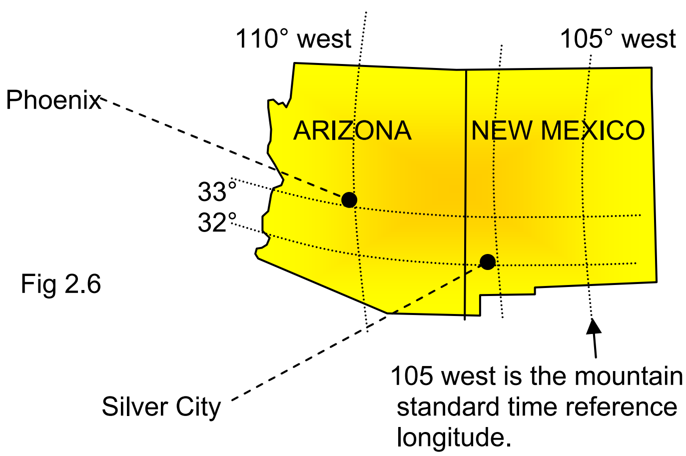


Fig 2.6

Things of interest to note are that when it is solar noon sun time on the 105 meridian (local apparent time or LAT), it will be appear earlier in Silver City and earlier still in Phoenix as far as sun time goes. Indicated sun time is called local apparent time, or LAT.

When it is solar noon on the Silver City meridian, LAT (local apparent time) it is later at the 105 meridian and earlier on the 112 meridian of Phoenix, sun time wise.

One degree of longitude is 4 minutes of LAT difference, which derives from the fact there are 360° going around the entire planet and there are 24 hours in the day or 1440 minutes.

The earth slows down and speeds up its rotation *around the sun* depending on whether the earth is further away from or nearer to the sun, and which way it is going. This means that sometimes the sun appears to be fast, and sometimes slow. Since hours nowadays are of equal length, dialists came up with a fictitious sun that were it to exist, would show perfect time. This "mean sun" differs from the real or actual sun by what is called "the equation of time", or EOT.

If the sun is fast, we subtract a correction, if the sun is slow, we add a correction. Some tables show "+" for fast meaning you "–" subtract the correction. And conversely show "–" if the sun is slow, meaning you "+" the correction. And some tables show the "–" or "+" directly so you always add the EOT value to local sun time to get the real mean time. Be wary of the sign, check it out.

Local Apparent Time (LAT) is solar time shown by the real sun at a particular place, the kind of time most sundials show. It needs two corrections before legal standard time is known.

One correction is the differences in longitude that affect the displayed time. Another correction is that measuring time using the real sun results in days of varying length. Instead of the real sun, we use an imaginary mean sun that moves at a constant speed equal to the average annual speed of the real sun. Thus we need to correct the real sun compared to the virtual or mean sun. That virtual sun, by the way, matches our clocks.

Mean Solar Time is a measure based on the virtual mean fictitious sun, it assumes that the earth's rate of rotation is constant. If you start real sun and the mean sun at a time when they coincide, over the next 12 months the mean sun will sometimes lag, sometimes lead the real sun, however at the end of the year they be back in synch.

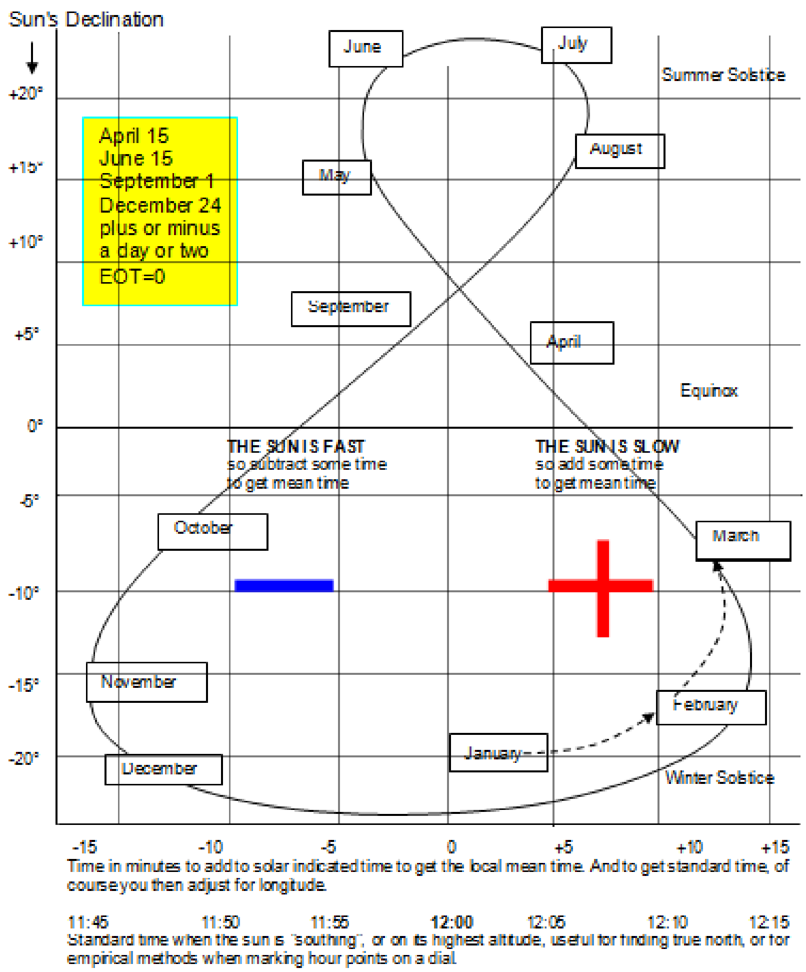
Local Mean Time (LMT) is solar time corrected for the Equation of Time but not for longitude, which is why it is called "local". The difference between the Local Mean Time and the Local Apparent time is known as the Equation of Time.

The Equation of Time (EOT) is the time difference between Local Apparent Time (apparent solar time) and Mean Solar Time at the same place. It varies between about +14 minutes in February and -16 minutes in October. The preferred usage by sundial enthusiasts is:

Mean Solar Time	= Apparent Solar Time + EOT
Standard legal time	= Mean Solar Time + longitude correction

This EOT sign convention is not standard and the opposite sign is used in some almanacs and web sites. Ignoring the sign convention used, the dial appears slow compared to the mean time in February, and fast in October/November. So in October you subtract an EOT number as the real sun is fast. In February you add an EOT number because the real sun is slow. EOT varies every second but is normally shown for noon each day. Mean Solar Time and the Apparent Solar Time match four times a year, i.e., the EOT is zero. The leap and the other three years are often averaged into the EOT tables, hence why key EOT dates seem inconsistent.

There is a software program called SHADOWS which can be used to double check sundial designs. It has a simulator feature that will show you the shadow moving, you can set it to any day and time. It has several displays of the equation of time, one is the figure of eight, one is the time lined graph, and another is a table. Here is my version of the figure of eight EOT.



Don't forget that for sundials to be accurate, longitude must be considered in addition to the equation of time, the longitude correction is a fixed number for a given place.

Sometimes the figure of eight chart may be seen on the hour lines of a sundial, this is called an analemma and is intended to provide graphical equation of time correction. It's presence can however make a dial look rather confusing.

In reviewing the sun's motion, the earth rotates on its own axis and the earth itself rotates around the sun, to the dialist we can consider that the sun rotates around the polar axis of the earth.

The gnomon's shadow producing edge (called style) for hour angle dials should point to true north and be parallel to the earth's polar axis. For altitude and azimuth dials, this is not relevant. From the picture above, it can now be seen that there is a simple geometrical relationship between the sun's motion around the earth, and the angles produced between the gnomon's style and also the sun's shadow. That geometry is for the most part simple and from that geometry comes the trigonometric method as an alternative method for building sundials.

Figure 2.7 shows a two gnomons, one east and one west, and why the shadow differs depending on location. This is the basis of longitude correction. One degree of longitude results in a 4 minute difference, this is because 24 hours times 60 minutes divided by the 360 degrees around the earth results in one degree for every four minutes.

As the sun gets closer to the earth on some days and further away on others caused by the elliptic as opposed to circular orbit, you can imagine that the shadow must change for the exact same time on those different days. This is corrected easily with the equation of time, or EOT.

Another correction is the daylight saving time, a political folly discussed earlier.

Figure 2.7 translates into simple geometry, discussed later, for dials that are horizontal or vertical facing true south or north, meridian dials (vertical facing true east or west), polar dials whose dial plate as well as their style are parallel to the earth's polar axis, and equatorial dials whose dial plate parallels the equator. There are all sorts of hybrids and variations in between, and they also use the sun's "hour angle", the angle the sun makes as it goes around the earth's polar axis.

Some dials use the sun's altitude, how high up it is, and not its hour angle, so they don’t need alignment with true north. These tend to be less accurate than hour angle dials.

Some dials use the sun's azimuth, how far east or west the sun is of the noon day shadow. Azimuth dials don't need a gnomon of an accurate length. These tend to be less accurate than hour angle dials.

LONGITUDE AND EQUATION OF TIME CORRECTIONS ARE NEEDED

The equation of time with the longitude correction see several typical uses. The most common use is when reading a sundial, the less common uses are when building one. Remembering:-

LAT local apparent time, time indicated by a sundial (sometimes also called true time)

EOT equation of time for the day, if the sun is fast compared to a clock (or the virtual or mean sun), then there is a minus correction, and if slow, there is a plus. Some tables show fast as plus, slow as minus. They are not wrong, they are designed by people who while otherwise normal, use a different convention. Many astronomers fall into this category.

Converting local apparent time to standard time is used when reading a dial:-

legal time or
standard time
or clock time =

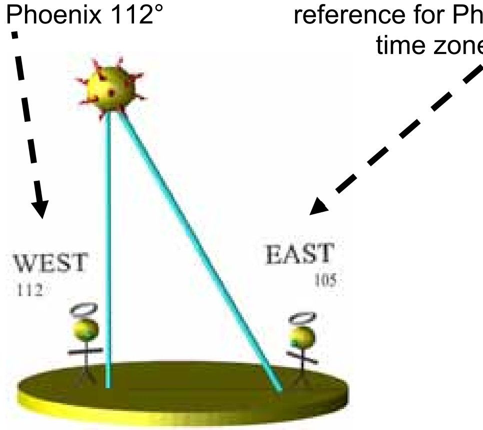
LAT +

EOT.corr
eg Nov –15
eg Feb +12

+ west.long.corr add if west of standard meridian
– east.long.corr subtract if east of standard meridian

+ 1 if summer

Phoenix 112° reference for Phoenix's time zone 105°



Phoenix AZ is at a longitude of 112° and is west of the standard time meridian for Phoenix covering Phoenix time which is at 105°.

When reading a dial with no built-in longitude correction in Phoenix, the longitude correction must be added because it is later at the 105° standard time longitude than in Phoenix at 112°. In other words, if west then add the longitude difference times 4 minutes per degree. If east you subtract.

Since Phoenix is 7° west of the reference longitude, being 112 minus 105, and remembering one degree equates to 4 minutes, that makes Phoenix show four times seven, or 28 minutes earlier than the legal time, so you add those 28 minutes.

For purposes of repetitive learning, all of October, November, and May the sun is fast so the EOT is negative, and in all of January, February, March, July, and August the sun is slow so the EOT is positive. There are four days when the EOT is effectively zero, they are somewhere near April 15, June 15, September 1, and December 25. The extreme values of the EOT are around February 11th when the sun is slow and the EOT is +14 minutes 12 seconds, and early November when it is fast and the EOT is now – 16 minutes 22 seconds. Other peak values are near May 13th and 14th when the sun is fast, so the EOT is –3 minutes 39 seconds, and July 25th and 26th when the sun is slow with an EOT of +6 minutes 30 seconds.

THE EARTH AND SUN INTERACT - EQUINOXES AND SOLSTICES

On the equator, at 0 degrees of latitude, every day is an equinox, that is to say that every day of the year has equal hours for day and night, regardless of whether the sun is overhead, or north or south of the equator. In the three pictures below the dashed arrow shows the earth's rotation. The pictures show the earth rotating on its axis, they suggest the earth tilts back and forth yearly. In fact the earth doesn't tilt back and forth as shown during the year, it only appears to do that because the earth retains its axis as it orbits around the sun, and that orbit around the sun is what causes the sun to appear to move above and below the equator.

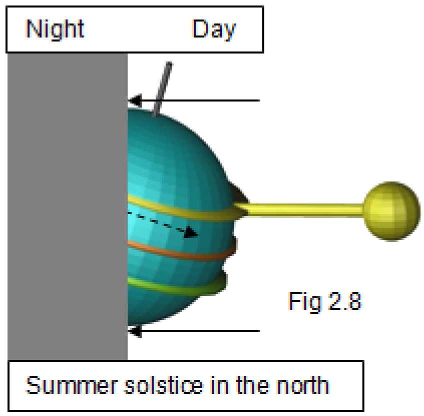


Fig 2.8

Looking at figure 2.8 the picture depicts summer in the northern hemisphere when the sun is north of the equator. As the sun's rays are parallel, the equatorial ray in the picture gets to travel the great circle around the equator. Because each place on the equator gets that ray, days and nights are of equal length. With northern visits of the sun, the sun always shines on the arctic, so the arctic has days with no night, and the bottom ray misses out on the Antarctic whose nights are dark, with no sun.

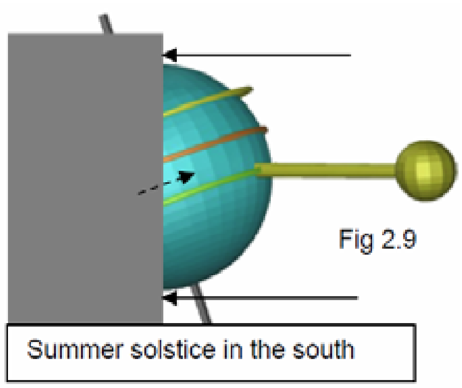


Fig 2.9

Figure 2.9 shows summer in the south, the Arctic is in permanent night, the Antarctic in permanent day, and the rays hitting the equator travel the great circle, so the equator still has days and nights of equal length.

Figure 2.10 shows March and September, when everywhere on earth has days equal to nights. The equinox happens around

March 21 and September 21, plus or minus a few days. The extremes of the sun moving north and south of the equator by 23.5 degrees are the solstices, December and June 21, shown in figures 3.4 and 3.5 respectively.

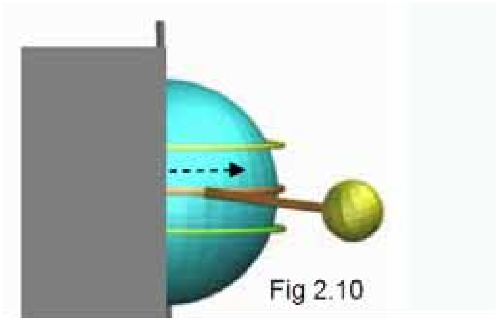


Fig 2.10

March or September ~ the equinoxes

The three figures have a line 90 degrees to the sun's rays, left of it is dark night time, right is bright day time. Assuming there are no clouds. The equator is always bisected, it is the north and south hemispheres that have an uneven division of time when the sun is not directly above the equator. The equator is a permanent equinox.

Notice the arrows in the summer pictures, they show how one pole endures a long night time, while the other basks in warmer temperatures.

To correct a sundial reading to find legal time, add something called the EOT (equation of time) to the indicated or local apparent time (LAT). The EOT is the difference between the real sun and a fictitious but constant sun (see next chapter). If the EOT is +5, then add 5 minutes to the dial's indication because the sun is slow . If the EOT were –3, you would subtract 3 minutes (add the minus 3 means subtract 3) from the reading because the sun is fast.

Local apparent time (what the dial shows)
+ EOT provides
Local Mean time
+ longitude correction provides
Standard Mean Time
+ 1 if summer and where applicable provides
Standard Summer time

A caution: some almanacs show the equation of time with opposite signs to those used here. To a dialist, a minus means the sun is running fast and needs the minus to "slow it down". To an astronomer, a minus means the sun is "slow" or "minus" and thus needs a plus to correct it. Neither is right, neither is wrong, it is just that astronomers and dialists have different perspectives.

In summary… The earth orbits the sun, its orbit is not circular but elliptical. That orbit, and the tilt of the earth cause the sun's apparent rotation around the earth to vary throughout the year. This is corrected with the equation of time, or EOT.

Latitude defines how north or south a place is compared to the equator. Longitude defines how far east or west a place is compared to a standard reference, which happens to be in Greenwich, England.

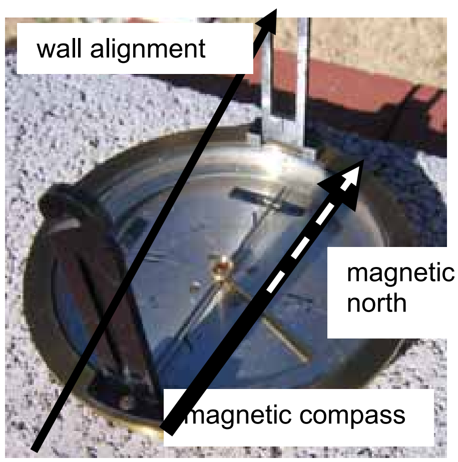
Time as shown by a dial is corrected for the slow or fast sun, then for longitude, and finally for summer time if appropriate.

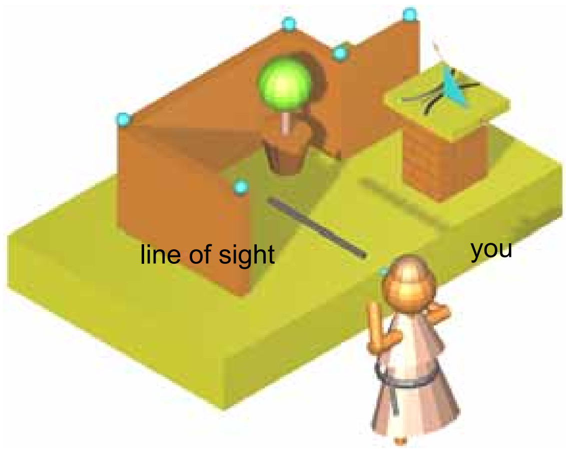
DETERMINING TRUE NORTH SINCE WE NEED THE POLAR AXIS

There are several methods of finding out where true north lies, and each has opportunities to screw it up. Some things to consider are that true north is usually not the same as magnetic north which varies over the years. Magnetic compasses are disturbed by local minerals, rebar in concrete block walls and proximity to automobiles; however the process is instant. The sun can give us the direction for true north, is not disturbed by local magnetic fields but the method takes either time or arithmetic, and no clouds. Surveys may have mistakes in them, be old and out of date. Stars require you to be able to identify them, and there are lots of them up there!

LOCAL SURVEY MAP METHOD ~ Some houses have survey maps drawn showing true north for buildings on the estate. These maps are often stylistic maps and layouts, so bearings are not that accurate.

MAGNETIC COMPASS METHOD ~ Acquire a compass and set it level, sight the surface upon which the dial and gnomon will be affixed, then note the magnetic bearing. Avoid being close to metal such as a car, a metal garage door, or a block wall which may have rebar.





Using this surveyor's compass, the sight by definition was 0 degrees, and the magnetic needle at this location showed 6 degrees to magnetic north. So the wall must be 6 degrees west of magnetic north, or 354 degrees magnetic. Then find the magnetic declination or variation, in Phoenix it is about 11 degrees east of true north, and then make an adjustment. An easterly magnetic declination means true bearings are more than magnetic ones, and westerly declinations means true bearings are less than the magnetic bearings. Thus for an 11 degree easterly variation, 354 degrees magnetic becomes 365 true, or subtracting 360 degrees, the wall is aligned at 5 degrees true. The wall declination is used for surfaces not aligned to true north, or true south, the convention is "The declination is named for the direction we face with our back to the wall". Thus making the wall above "north 85 degrees west".

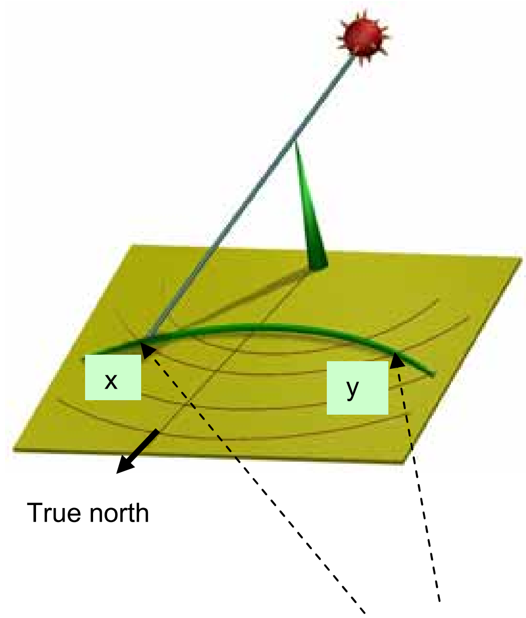
Magnetic variation is printed on most maps, and is published in almanacs and available on the web. Web sites are found by searching on "magnetic north variation".

SOLAR METHOD ~ THE SUN CROSSES AN ARC BOTH AM AND PM

The compass method uses simple math, a compass and is quick, but the compass can be swayed by nearby metal, such as wall reinforcements, and it is easy to make a mistake in the math unless you draw pictures (see the appendix).

The solar method is slow, and requires a level surface. To the left is a photo of a dial plate with a vertical pin, except circles are drawn around the pin. The surface is leveled with bits of wood between the upturned bucket and the dial plate. The compass is not used except as a rough and ready quick start to get the dial plate roughly pointing in the right general direction.

You begin before lunch, and note when the sun's shadow crosses an arc. And you come back in the afternoon and see when it crosses it again.



The sun crosses the circle at x and y. You draw a line from the center to x and to y, then bisect the angle. The bisected arc's center points to true north. The equation of time has nothing to do with this as it doesn’t matter if the sun is slow today or fast. The sun orbits around the earth's polar axis and that is what is actually being measured, not the time. In reality you do several circles and average the results, and several circles reduces the chances of a cloud shadowing things and ruining your afternoon.

SOLAR METHOD – WHEN THE SUN IS EXACTLY AT SOLAR NOON

The longitude, equation of time, and summer time corrections for converting local apparent time into to legal standard can be used to identify true north.

Local apparent time (what the dial shows)
+ EOT provides
Local Mean time
+ longitude correction provides
Standard Mean Time
+ 1 if summer and where applicable provides
Standard Summer time

Solar noon indicates true north because the sun is at its highest point. Thus the shadow produced at solar noon will point to true north. Solar noon happens at the standard time adjusted as follows:-

12:00:00 + EOT + 1 (if summer) +

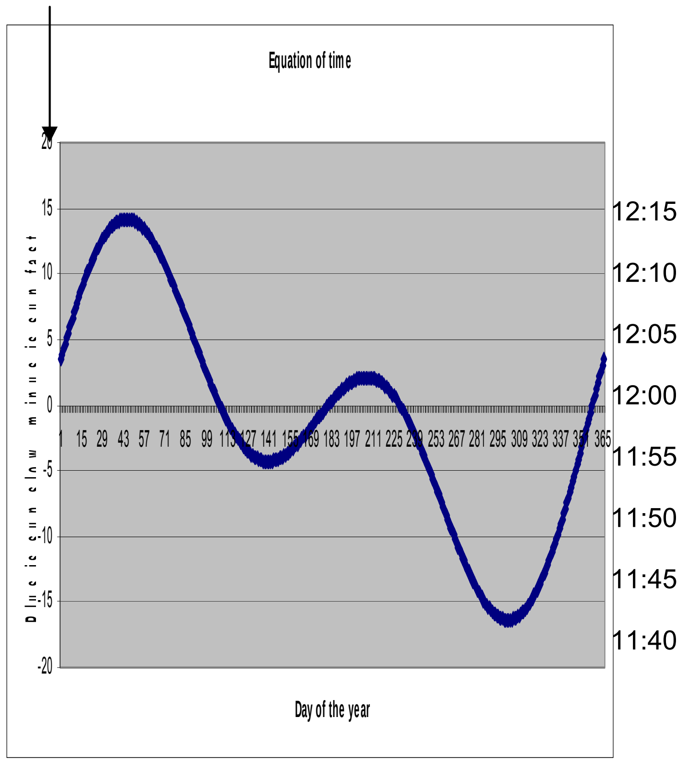
longitude correction =legal time for solar noon

Silver City is longitude 108.2 west, and is thus 12m 48 seconds west of the meridian of 105 degrees. So to find the legal time for when the sun is at high noon, we add 12m 48s (we are west of the meridian), thus get 12:12:48 on the clock for a Silver City high solar noon. That takes care of the longitude correction. However we must correct for a slow or fast sun.

And on November 12 the equation of time shows the correction to be "–15:46" which is minus because the sun is running fast by 15 minutes and 46 seconds. We subtract the 15:46 correction so our time catches up with the sun.

radio noon on the 105 degree meridian:		12:00:00
longitude correction:	+	00:12:48
if we are west then add		
result	=	12:12:48
equation of time correction	–	00:15:46
use EOT table's sign		
result	=	11:57:02

Time when the sun will be on the standard noon meridian



The beauty of the equation of time and its associated formula is that the techniques discussed in this book do not involve reversing the signs of the EOT, nor reversing the signs of the longitude correction. There are two caveats when using this method to locate true north.

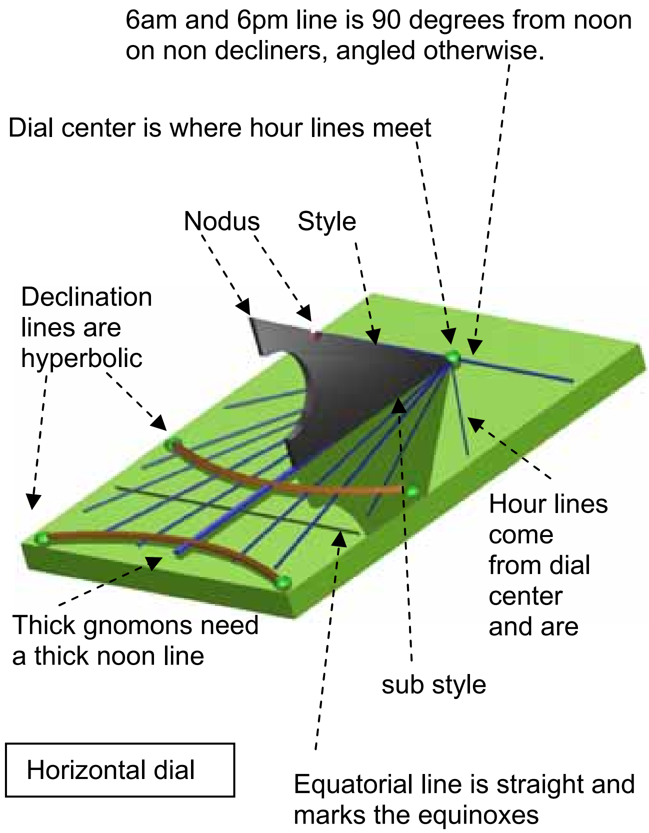
The first is that is that the equation of time is not fixed that accurately. First, the tables provided in this book are averages over a four year period. And over the decades, centuries, and millennia, the equation does change. The moral of the story is that the dialist should ascertain the equation of time as accurately as possible. Web sites have online almanacs for just this purpose, however be aware that many astronomical web sites show a "+" meaning sun is fast, and a – meaning sun is slow, in which case the sign must be corrected for the sun dial convention which is + for a slow sun because the EOT value must be added. Those web sites are not wrong, but check the sign before using the standard sundial EOT convention.

The second is that longitude is significant. For example, the time in seconds between the east end of runway 8 at Phoenix Sky Harbor International Airport, and the west end is 10 seconds. And 13.5 miles is one minute. A city that is 50 miles across will have a local apparent time difference of 3.75 minutes.

Accuracy in longitude and accuracy in the precise equation of time are as critical in this method, as is the accuracy of the clock employed.

SUNDIAL CONSTRUCTION AND KEY POINTS

Below is a horizontal dial layout. They have a dial plate upon which things are inscribed or placed, such as hour lines, declination lines and so on, called furniture.



The shadow casting assembly is called a gnomon, its angled edge which casts the shadow is the style. The bottom of the gnomon attached to the dial plate, is the sub-style. An optional notch or blob is called a nodus indicating the calendar. Wooden gnomons warp, thick gnomons need consideration of which part of the shadow to use, holes in a gnomon can reduce wind resistance. Gnomons should not be used to catch horseshoes. The gnomon, hour lines, and the furniture such as calendar lines) rest on the dial plate. The hour lines which indicate the time originate from the dial center.

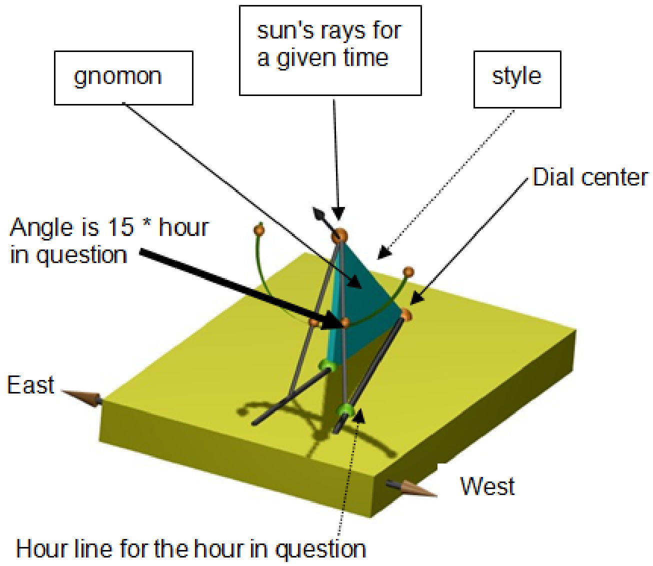
The calendar, is often marked by three lines. The curves (hyperbolae) are solar declination lines and often show the solstices (December 21, June 21, approximately), and the straight line marks the equinoxes (March 21 and September 21, approximately). The 21st of March, June, September, and December are the conventional days for the solstices and equinoxes, however a few days either side are sometimes used.

Accurate dials are designed for a specific latitude, the hour lines depend on it as does the angle between the style and the sub-style (style height). Since sundials are seldom on the legal time meridian, they need longitude correction to either be built in, or require some mental arithmetic. The sun appears to be slow or fast at times, so dials need to be corrected for what is called the equation of time. These corrections can be designed into the dial, or provided as a table for the user to mentally adjust the displayed time to legal time.

A HORIZONTAL DIAL

The horizontal dial spends its life perfectly level. The gnomon is always aligned to true north, and it's style is always parallel to the earth's polar axis, so the sun revolves in a circle around that style. That means that the style forms an angle with the sub-style that is equal to the latitude.

The style is at the latitude angle, and points true north.



Latitude affects the style, and thus the hour lines. The noon hour line should be an extension of the sub-style if longitude correction is not built in. Longitude corrections made to cause the LAT (local apparent time) to match the legal meridian result in the noon line no longer being an extension of the sub-style line. To make the dial perfectly match legal time, we must also account for the equation of time.

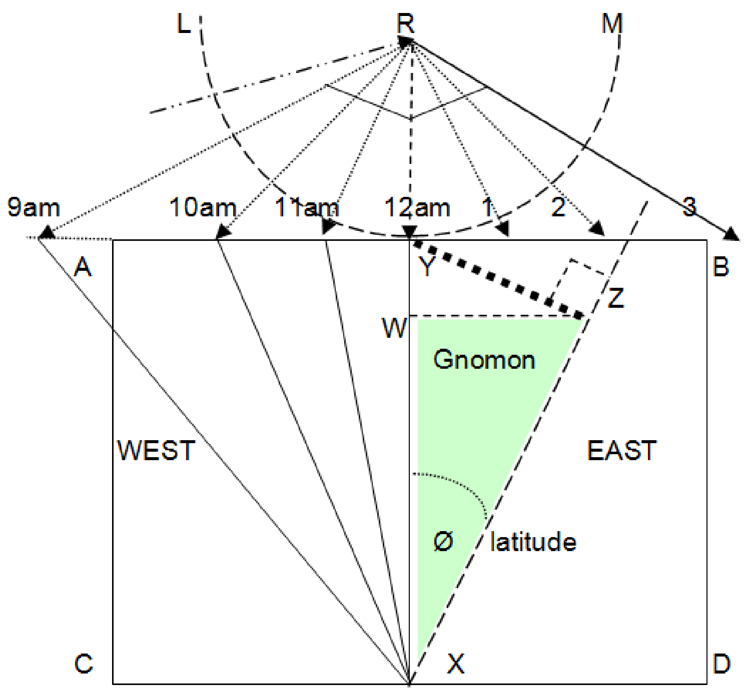
THE GEOMETRICAL METHOD FOR A HORIZONTAL DIAL

Consider a dial plate ABCD. In its center draw a noon line XY. From X draw a line XZ that makes an angle with XY equal to the latitude. In essence this is the gnomon's style rotated 90 degrees and thus is lying flat on the surface of the dial plate as if the wind blew it over, resting peacefully.

Draw a line perpendicular to the style that goes to Y, that point on the style is labeled Z. Or, from Y draw a line to Z, the angle XYZ being the co-latitude, and thus intercepts the style at 90 degrees.

Our gnomon is WXZ when rotated back vertically. ZY is the path the sun's rays travel at the equinox at solar noon.

Rotate YZ to the top as YR, and then draw a semi-circular protractor LYM centered on R.



To make the pictorial readable, the 15 degree angles are spread out and are not to scale.

See the full version of this book for hours further away from noon.

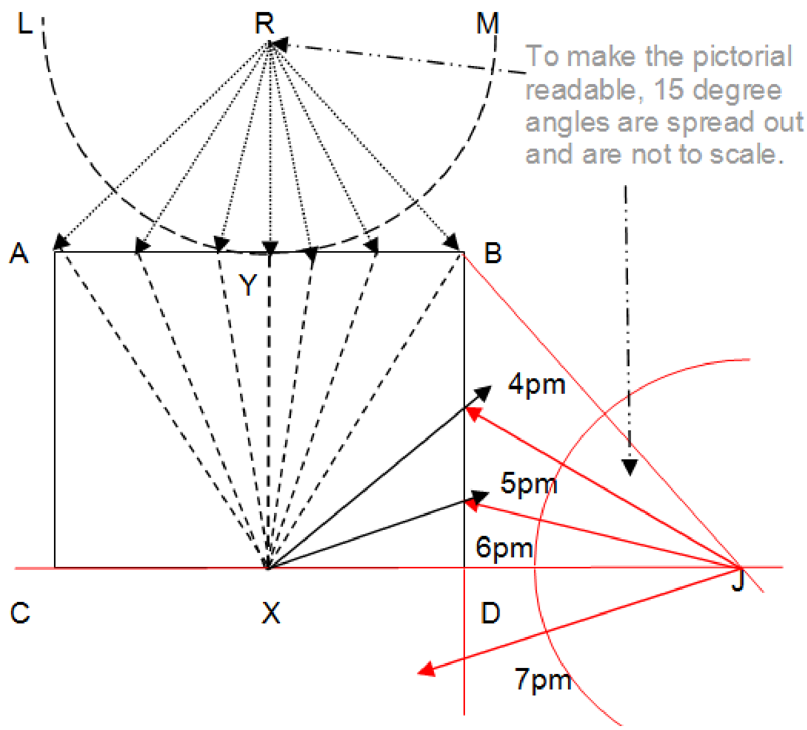
Then mark off 15 degree marks on the protractor LYM, and extend the protractor's 15 degree lines to AB. Finally, the hour lines are drawn from the dial center up to where the protractor lines meet the west to east line AB.

The equation of time, EOT, is managed mentally by a printed table for the sundial observer to consider, and the longitude correction can be folded in to that table.

A technique for hours some time off from noon

Extend the 45 degree line RB and the plate bottom line CD so they meet at J, similarly on the other side. Or, make a line XJ equal in length to XR. Drop perpendiculars from A to C and from B to D so that intersections for the early and late hours can be drawn on lines AC and BD.

At those new centers J and on the other side, draw a protractor and mark off the 15 degree arcs and have them intercept BD and AC.



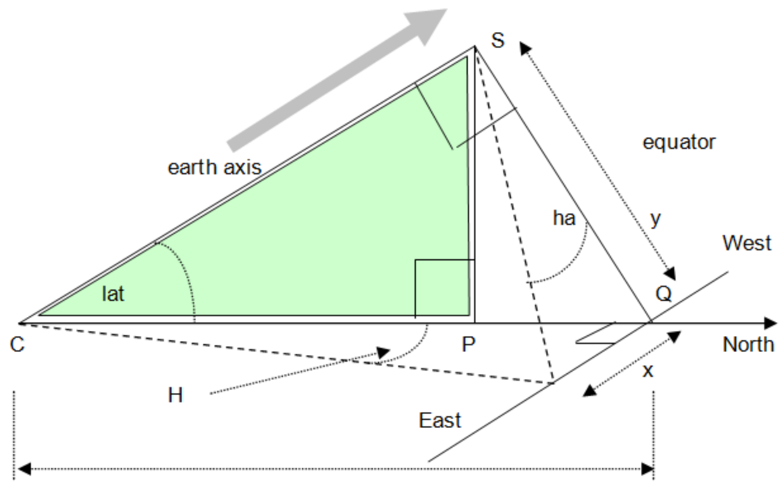
The protractor process is repeated on the other side. This provides the 4, 5, and 6pm lines, even 7pm and 8pm. Similarly the 4am, 5am, 6am, 7am, and 8am lines.

This technique has the benefit of being able to draw hour lines whose distance along "AB" would be excessive using the simple single protractor approach.

THE TRIGONOMETRIC METHOD FOR HORIZONTAL DIAL HOUR LINES

To calculate any hour line from the sub style:

H = arctan (sin (lat) * tan (ha))



(1)	tan (ha) = x/y	tan of hour angle (15 degrees * hour)
(2)	x = y * tan (ha)	thusly
(3)	tan (H) = x/z	tan of the hour line angle
(4)	sin (lat) = y/z	sin of latitude or Ø
(5)	y = z * sin (lat)	thusly

(6) H = atan (x/z) = atan ((y * tan (ha)) / z)
= atan ((z * sin (lat) * tan (ha) / z))
= atan (sin (lat) * tan (ha))

So, any hour line from the sub style: H = arctan (sin (lat) * tan (ha))

The hours used in the hour line formula may be adjusted for longitude. If you use a spreadsheet then trigonometric functions use radians, and must be converted back using degrees. The formula is then something like:-

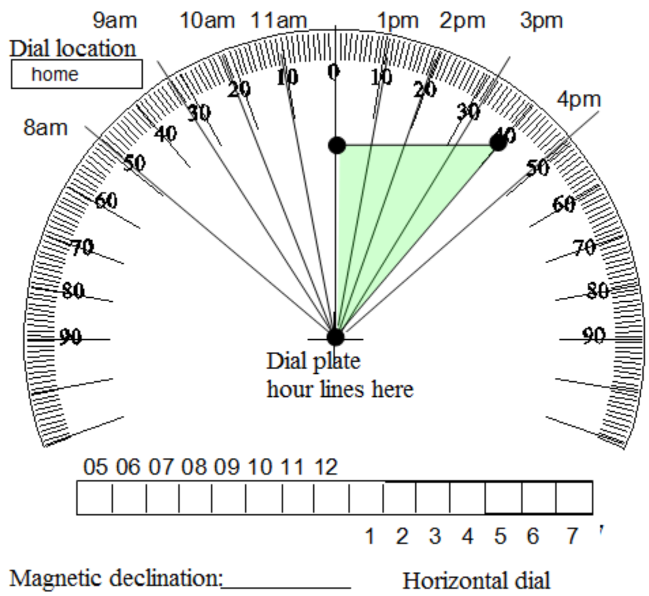
```
DEGREES(ATAN(TAN(RADIANS(15*time))*SIN(RADIANS(latitude))))
```

Tables can be used which are trigonometric in nature

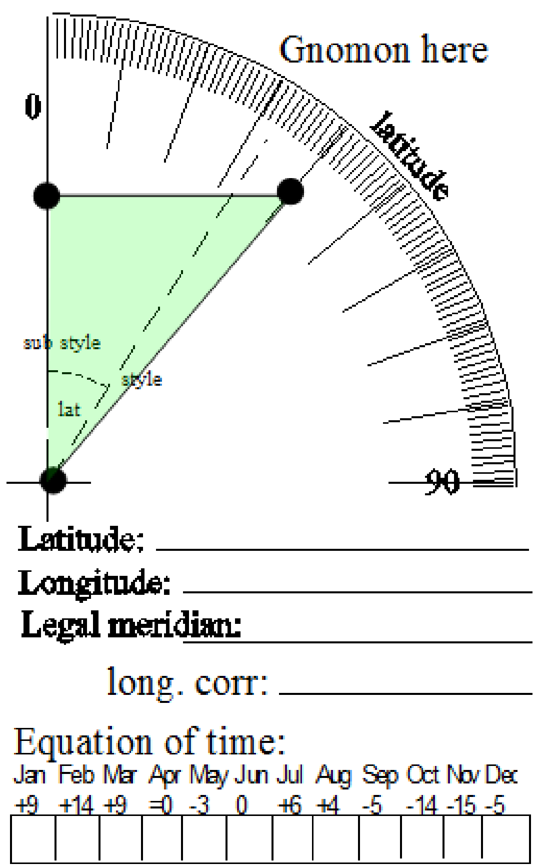
Appendix 3 has tables with hour line angles calculated for various latitudes.

HORIZONTAL DIAL: Method: Using Tables

Protractor for the hour lines...



Protractor for the gnomon...



Appendix 3 table A3.1b for latitude 40 provides the following hour line angles assuming no longitude correction.

8am and 4pm   48.07 degrees

9am and 3pm	32.73 degrees
10am and 2pm	20.36 degrees
11am and 1pm	9.77 degrees etc

The hour lines before and after noon are drawn. The gnomon is drawn and moved to dial center. The longitude correction of 4 degrees (at 4 minutes per degree) is 16 minutes, and is west of longitude 105 thus we must add the time. The longitude correction of 16 minutes is added to the equation of time, producing:-

Jan	Feb	Mar	Apr	May	Jun	Jly	Aug
	Sep	Oct	Nov	Dec			
+25	+30	+25	+16	+13	+16	+22	+20
	+11	+2	+1	+11			

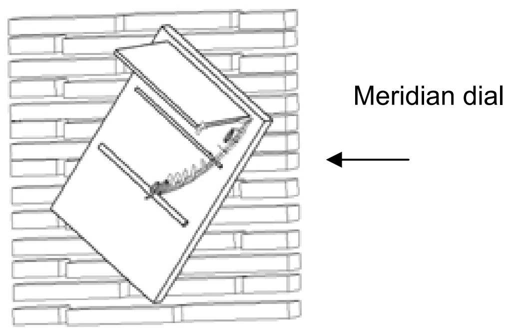
The dial plate is aligned to true north, and the shadow is mentally corrected with the revised equation of time (EOT).

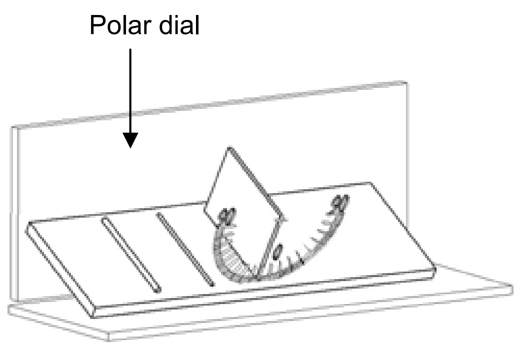
Alternatively the hour lines could be adjusted individually for longitude, however the dial would no longer be portable. If the hour lines were longitude adjusted, they would simple be rotated, but by an angle calculated for a time corrected by the 16 minutes, one hour line at a time. The equinox line is derived by extending the gnomon from the nodus to the sub-style line extended, and perpendicular to the style. Longitude corrections of 4 or more degrees cause the resulting combined EOT table to always have the same sign. That is because 4 degrees is 16 minutes, the maximum EOT deviation. This paper dial can be tested in the sun before the final dial is built as is shown in the inset.

DIALS WHOSE PLATE IS AT LATITUDE
(POLAR DIAL)

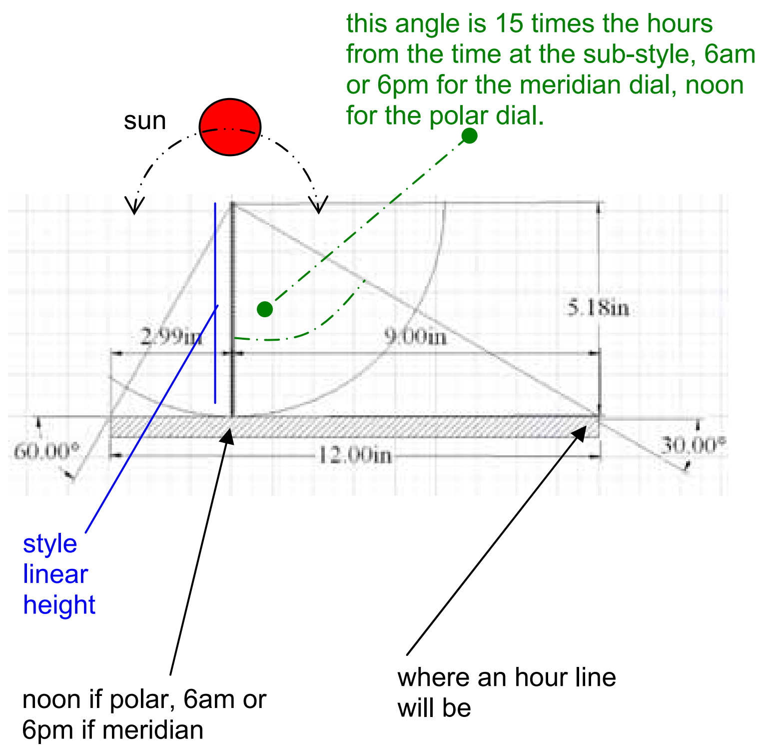
AND
POLAR DIALS THAT ARE VERTICAL BUT SLOPED AT LATITUDE
(MERIDIAN DIALS)

The meridian dial, below and to the left, and the polar dial, below and to the right, all use the same theory of design.





The sun rotates around the gnomon's style at 15 degrees per hour. Thus each hour line is always a distance from the sub-style or base of the gnomon, by a distance equal to the sub-style to style linear height multiplied by the sun's hour angle. The sun's hour angle is 15 degrees per hour.



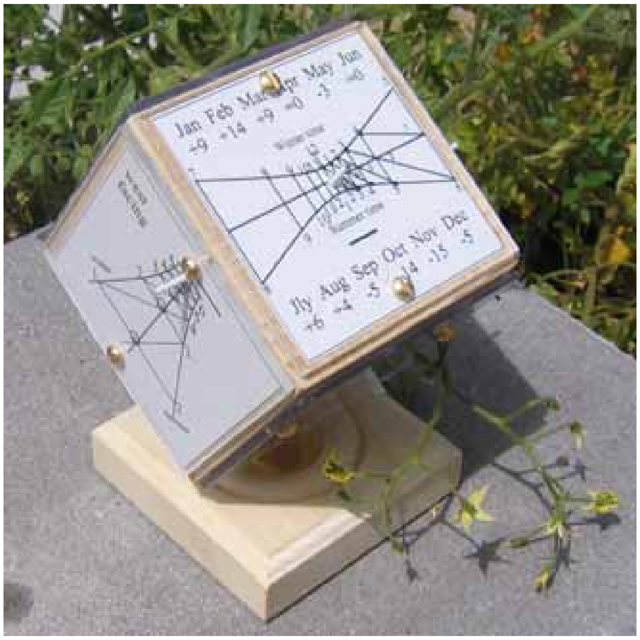
The two headed arrow above is the distance from the sub-style to the hour line, and it's distance is:-

linear style height * tan (hour from the sub-style * 15)

What is the reference hour at the sub-style? It is 6am or 6pm for east and west facing dials, and 12 noon for polar dials.

Many books use the same time as a reference for the meridian as well as th polar dials, so the formula looks different. This book uses 6am and 6pm for meridian dials that face true east and west, and noon for polar dials.

CUBIC DIALS



This booklet has in mind two cubic dials.

The first is on the left and using the template, it works at any latitude provided the sub is tilted to the dial's latitude. It requires north south alignment.

The second is below and to the right, the dial is typically designed for a latitude in so far as the horizontal and vertical dials are latitude specific. The meridian (east and west) dials are tilted so their equinox line is at the co-latitude.

In all cases, if sunset data is to be displayed, then that makes the dial latitude dependant.

The horizontal dial – on top of the cube to the right, has been discussed and the reader is proficient in it's design. The vertical dial to the right is designed exactly as would be a horizontal dial however the co-latitude is used in place of the latitude.

That only leaves the meridian dials which are on the east and west faces, which are common to both cube dials on this page, and the polar dial (the one facing the sun in the top picture) and the equatorial dial which is not visible in the top picture.

The meridian dials (east and west) have the same design method that a polar dial has. Hour lines are always a distance from the gnomon base equal to the linear height of the gnomon multiplied by the trigonometric tangent of the product of the hour and 15. The 15 is because the sun rotates 15 degrees per hour. And the equatorial dials are nothing more than circles with hour lines every 15 degrees.

Above are the materials, other than the templates, that make the dial.

Some wood 4 by 4 beams are not true square, so check where the "bad" side is, and use that for a plate that will not have a dial face on it.

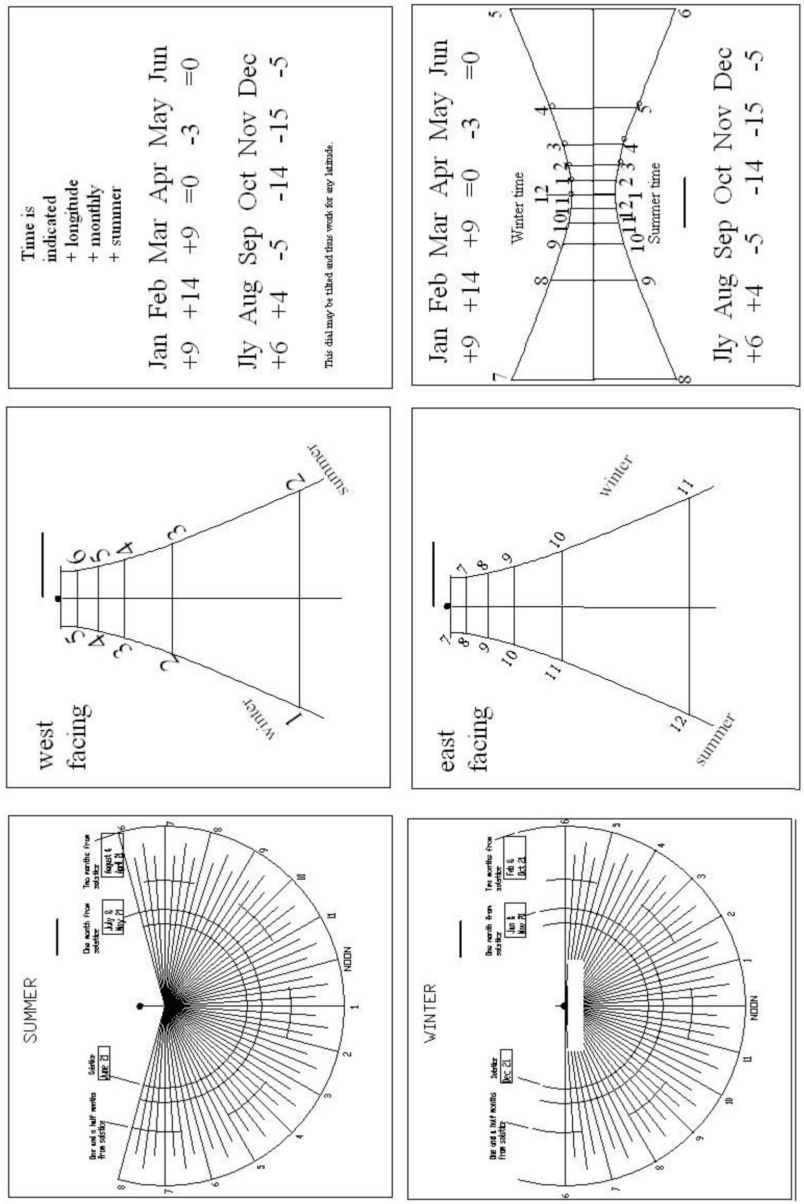
Plexi-glass was used, clear contact paper can also be used however it is less durable.

Below to the left are some tools. One is a metal protractor useful for marking the two pencil lines on the wooden block to help guide the trueness of the hole, namely at co-latitude. Three drill bits are helpful, a small one to drill the plexi-glass foe the nail gnomon, another for screws to hold the plexi-glass, and as a starter hole for the dowel, and a third for the holes in the cube and base for the dowel itself. A measuring device or micrometer is used to measure the wood block faces, and to measure the height of the gnomon nails whose length is on the template. If plexi-glass is used, remember to consider the thickness of plexi-glass. The snips are to cut the nails to the correct length. A utility knife is used to cut plexi-glass as well as the templates.

Take care when using utility knives, they can cut the fingers and you may not know it until you see visible signs of human trauma.

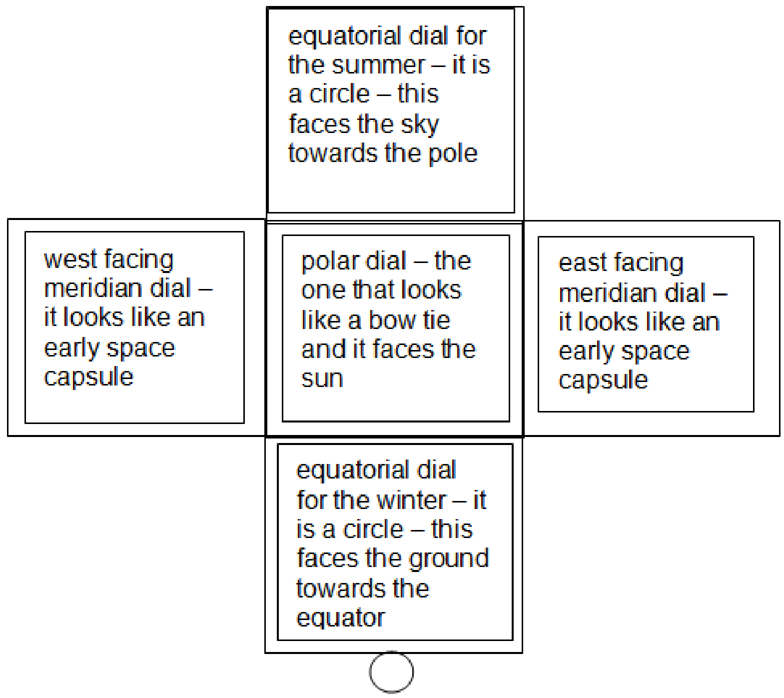
If the screws and nails are not brass, then be aware that a compass in close proximity may not be accurate.

TEMPLATE FOR THE FIRST CUBIC DIAL



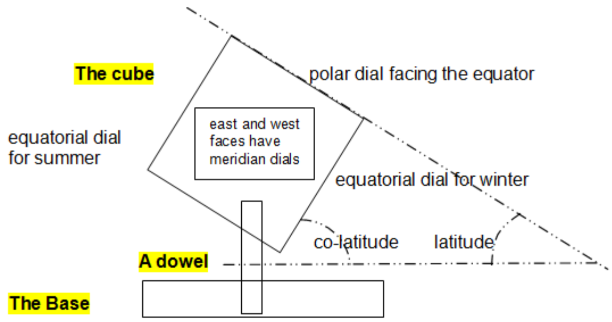
BUILDING THE FIRST CUBIC DIAL

A cube of wood cut from a 4 by 4 inch beam is the cube.



The template is cut and may be glued to the cube using Elmer's glue or even PVC pipe glue. Remember that glue fumes may be toxic.

A base is cut from a 1 inch thick 4 by 4 inch beam. A hole is drilled in the base, and a hole in the cube. The hole in the cube is on the cube face that faces the pole and faces the ground. If it has anything on it, it would be just data, such as in the top left of the template on the preceding page.



The hole in the cube is at an angle, and to facilitate this, mark the east or west face with a line angled at co-latitude (90-latitude), and mark the equatorial face with a vertical line. Use a small drill first and have the drill match the co-latitude line and the vertical line. When that hole is finished, insert a nail or rod and check for true angles. Then use a bigger drill bit to make room for the dowel.

Then attach the dial faces. They may be protected with clear contact paper or with plexi-glass which would be screwed t the cube faces.

Then insert nails to be the nodus which functions as the entire gnomon.

The height of the nail from the wood surface to the nail tip is shown on each dial template as a horizontal line. SO if you scale up or down the template, the gnomon length will change appropriately.

Glue the cube to the dowel and the down to the base.

You now have a dial reading local apparent time.

Add or subtract the longitude correction, being 4 minutes per degree from the legal time meridian.

Add the EOT factor, it is on the dial face, however a more complete table is in the appendices.

The dial is now functional.

BUILDING THE SECOND CUBIC DIAL

The second dial has no complicated holes to drill at a special angle for latitude. The meridian dials can come from the prior template, that leaves just the horizontal dial to draft and an SIMPLE SHADOWS covers that. The vertical dial is nothing more than a horizontal dial but designed for the **co-latitude**

co-latitude is 90 - latitude.

QUESTIONS

The gnomons are all nails, so, where is the style? The style is virtual, thus the nail length and position for the vertical and the horizontal dials are such that were a line extended from the nodus or tip to the dial center, then latitude would be apparent.

Some data on the templates is latitude dependant, but the time is not, provided the instructions are followed.

For full information on these refinements, please acquire Illustrating Time's Shadow!

APPENDIX - 1

TRIGONOMETRY BASICS

Trigonometry has a set of functions that are defined that make working with angles and lines easy using simple mathematics. There are also certain truisms about the functions.

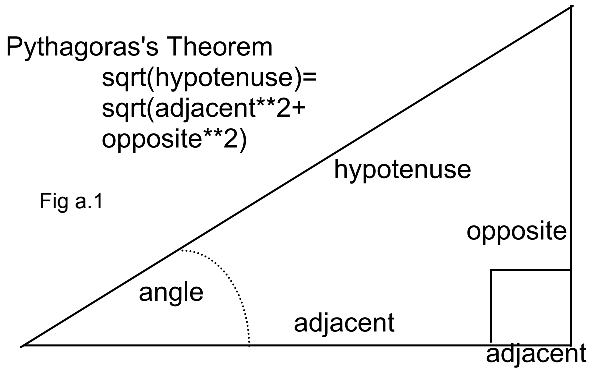


Fig a.1

A right angles triangle has one angle that is 90 degrees, and the side opposite that angle is called the hypotenuse. For an angle other than the right angle, there are defined sides called the opposite side and the adjacent side.

And there are some predefined functions, and tables that give you their values. And spreadsheets provide this service also, however a spreadsheet usually uses "radians" rather than the more common degrees.

definitions:

tan (angle)	=	opposite /adjacent	[tangent]
sin (angle)	=	opposite / hypotenuse	[sine]
cos (angle)	=	adjacent / hypotenuse	[cosine]

and they are remembered with the sentence: "the old aunt, sat on her, coat and hat". The word "co" means complement of. So the cosine is the complement of the sine.

cos (angle) = sin (90 - angle)

And for the tangent some extra things are true…

cotan(angle) = tan (90 - angle)
= 1 / tan (angle) is easily proved
because 90-angle is the opposite angle

and thus its tan is the old adjacent divided by the old opposite.

Also you can deduce:

tan (angle) = sin (angle) / cos (angle)

The angle whose sine is x is referred to as arcsin(x), similarly for arcos and arctan, or asin, acos, and atan. Sometimes the symbol $\sin^{-1}$(value), $\cos^{-1}$, and $\tan^{-1}$ are used.

GEOMETRYBASICS

Geometry is the drawing of lines, arcs, circles and the like. It relates to trigonometry, however it can be used independently.

Geometry can also use techniques such as rotating something on its side, such as a protractor on a gnomon, whereas doing that rotation in trigonometry would be much harder since it would involve three dimensions.

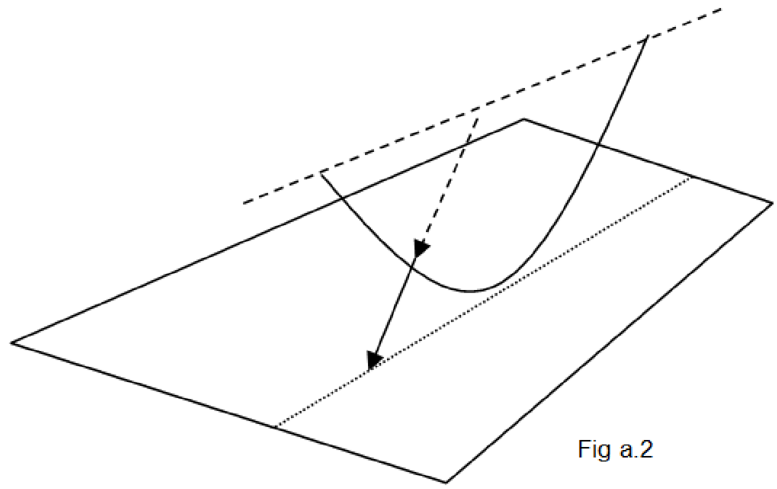


Fig a.2

For example, above we see a protractor perpendicular to a plane and it has some angle marked. With geometry we can fold the protractor down to be in line with the plane which makes things much easier.

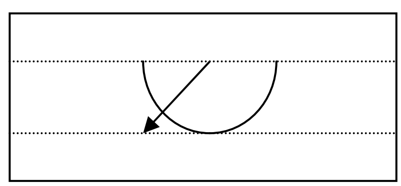


Fig a.3

And these projections are very helpful in working out sundial problems. Where geometric methods were used, they were nothing more than rotations of planes by sometimes 90 degrees, sometimes by less.

CAUTION: Some projections are not just 90 degree rotations. For example, in the horizontal dial, the gnomon is rotated 90 degrees first, and then a 90 degree line drawn from the nodus to the plate, and that is then rotated more than 90 degrees in effect, because the protractor's radius is the 90 degree line from the nodus and not the vertical dropped from the nodus to the dial plate.

The protractor's radius comes from rotating the 90 degree projection of the style by 180 degrees - latitude

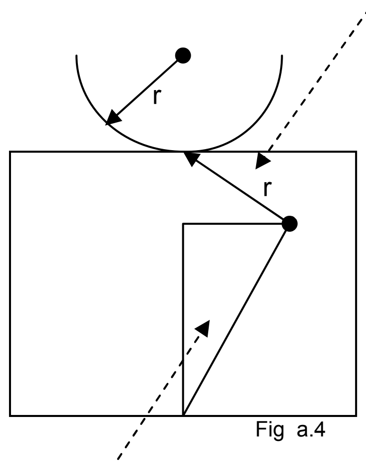


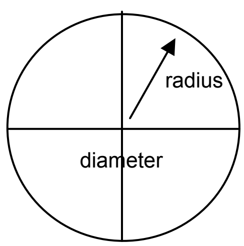
Fig a.4

But first the gnomon is rotated only 90 degrees.

TRIANGLES AND THINGS

All normal (i.e. non spherical) triangles have angles that add up to 360 degrees, a right angled triangle has one angle of 90 degrees, and an isosoles triangles has two of the angles equal and thus less than 90 degrees, and an equilateral triangle has all three angles equal and they are 60 degrees each.

CIRCLES AND THINGS



circumference is the length of the perimeter.

A circle has a center, and the perimeter of the circle is a constant distance from the center, that distance is called the radius.

The diameter is the distance between two points on the perimeter , or circumference, passing through the center, and is twice the length of the radius.

The length of the perimeter, it's circumference, is:-

circumference = 2 * 3.1416 * radius
circumference = 3.1416 * diameter

The number 3.1416 is called pi, symbol π, and occurs in many circular mathematical expressions.

The circumference is divided up into degrees, degrees of arc, and there are 360 degrees in a circle, or 180 degrees in a semi-circle. Other measures are used, the next most common, especially when using spreadsheets, is the radian. There are 2 * pi , i.e. 2 *3.1416, or 6.2832 radians in a circle, so one radian is 57.296 degrees. That strange number actually makes sense when it is found that the trigonometric functions of sin, cos, and tan are derived from series, and readily employ the radian.

sin(x) = x – (x**3)/3! + (x**5)/5! – (x**7)/7! + . . .

cos(x) = 1 – (x**2)/2! + (x**4)/4! – (x**6)/6! + . . .

tan(x) = x + (x**3)/3 + 2*(x**5)/15 + . . .

atan(x) = x – (x**3)/3 + (x**5)/5 – (x**7)/7 + . . .
(no factorials)

While the series shown above may not be used much in the normal course of life, they were what the author used back in the IBM 360 and early 370 days when developing font rotation logic using the floating point feature of the computer.

The symbol "!" is called a factorial, and is simply a string of multiplications from the number in question down to 1, thus 5! would be 5*4*3*2*1 or 120 if my arithmetic serves me well today.

APPENDIX 2 - Tables independent of location

A2.1

EQUATION OF TIME ~ EOT

If "+" then add to solar time to get mean time as the sun is slow. If " –" then subtract from solar time to get mean time as the sun is fast. Some tables have a plus for our minus and vice versa. If in doubt look at the figure of eight equation of time. **Formulae involving dates** use approximations thus these tables may disagree with other sources using other formulae. This and other publications have figures that are well within drafting tolerances.

	5th	15th	25th	EOT $_{=0}$
JAN	5.1	9.0	12.0	
FEB	13.9	14.2	13.4	
MAR	11.9	9.3	6.3	
APR	2.8	0.0	-2.3	4/15
MAY	-3.6	-4.0	-3.5	
JUN	-2.0	-0.1	2.0	6/15
JLY	3.9	5.3	5.9	
AUG	5.4	3.8	1.4	
SEP	-2.2	-5.8	-9.4	9/1
OCT	-12.7	-15.1	-16.5	
NOV	-16.5	-15.1	-12.5	
DEC	-8.8	-4.5	0.2	12/25

A2.3

LONGITUDE TO TIME

Degree (°) to Hours (h) and Minutes (m)

°		°		°		°		°		°	
0	0.00	30	2.00	60	4.00	90	6.00	120	8.00	150	10.00
1	0.04	31	2.04	61	4.04	91	6.04	121	8.04	151	10.04
2	0.08	32	2.08	62	4.08	92	6.08	122	8.08	152	10.08
3	0.12	33	2.12	63	4.12	93	6.12	123	8.12	153	10.12
4	0.16	34	2.16	64	4.16	94	6.16	124	8.16	154	10.16
5	0.20	35	2.20	65	4.20	95	6.20	125	8.20	155	10.20
6	0.24	36	2.24	66	4.24	96	6.24	126	8.24	156	10.24
7	0.28	37	2.28	67	4.28	97	6.28	127	8.28	157	10.28
8	0.32	38	2.32	68	4.32	98	6.32	128	8.32	158	10.32
9	0.36	39	2.36	69	4.36	99	6.36	129	8.36	159	10.36
10	0.40	40	2.40	70	4.40	100	6.40	130	8.40	160	10.40
11	0.44	41	2.44	71	4.44	101	6.44	131	8.44	161	10.44
12	0.48	42	2.48	72	4.48	102	6.48	132	8.48	162	10.48
13	0.52	43	2.52	73	4.52	103	6.52	133	8.52	163	10.52
14	0.56	44	2.56	74	4.56	104	6.56	134	8.56	164	10.56
15	1.00	45	3.00	75	5.00	105	7.00	135	9.00	165	11.00
16	1.04	46	3.04	76	5.04	106	7.04	136	9.04	166	11.04
17	1.08	47	3.08	77	5.08	107	7.08	137	9.08	167	11.08
18	1.12	48	3.12	78	5.12	108	7.12	138	9.12	168	11.12
19	1.16	49	3.16	79	5.16	109	7.16	139	9.16	169	11.16
20	1.20	50	3.20	80	5.20	110	7.20	140	9.20	170	11.20
21	1.24	51	3.24	81	5.24	111	7.24	141	9.24	171	11.24
22	1.28	52	3.28	82	5.28	112	7.28	142	9.28	172	11.28
23	1.32	53	3.32	83	5.32	113	7.32	143	9.32	173	11.32
24	1.36	54	3.36	84	5.36	114	7.36	144	9.36	174	11.36
25	1.40	55	3.40	85	5.40	115	7.40	145	9.40	175	11.40
26	1.44	56	3.44	86	5.44	116	7.44	146	9.44	176	11.44
27	1.48	57	3.48	87	5.48	117	7.48	147	9.48	177	11.48
28	1.52	58	3.52	88	5.52	118	7.52	148	9.52	178	11.52
29	1.56	59	3.56	89	5.56	119	7.56	149	9.56	179	11.56
										180	12.00

A2.5

CITY DATA WITH LATITUDE, LONGITUDE AND ITS CORRECTION

City id				Lat +n -s	Long +w -e	Mag var	Time ref	Long corr
	UK		London	51.5	0.5	2.5w	0	2
	UK		Weymouth	50.6	2.5	3.4w	0	10
PHX	USA	AZ	Phoenix	33.5	112.0	11.8e	105	28
SDL	USA	AZ	Scottsdale	33.6	111.9	11.8e	105	27.6
LAX	USA	CA	Los Angeles	34.0	118.3	13.4e	120	-6.8
SAN	USA	CA	San Diego	32.8	117.2	13.1e	120	-11.2
SFO	USA	CA	San Fransisco	37.8	122.5	15.4e	120	10
DEN	USA	CO	Denver	39.8	105.0	10.2e	105	0
DCA	USA	DC	Washington	38.9	77.0	10.3w	75	8
CHI	USA	IL	Chicago,	41.8	87.8	2.2w	90	-8.8
SVC	USA	NM	Silver City	32.8	108.2	10.6e	105	12.8
LAS	USA	NV	Las Vegas	36.2	115.2	13.3e	120	-19.2
JFK	USA	NY	New York	40.7	73.8	13.8w	75	-4.8
ELP	USA	TX	El Paso	31.8	106.5	10.1e	105	6

A2.6

DAYLIGHT SAVING TIME AND TABLE OF TIME ZONES

Zone	Name	Meridian		GMT+
	Newfoundland	52.5		3.5
4	Atlantic	60		4
5	Eastern	75		5
6	Central	90		6
7	Mountain	105		7
8	Pacific	120		8
9	Yukon	135		9
10	Alaska-Hawaii	150		10
11	Bering	165		11
	GMT Greenwich Mean Time			0
	BST British Summer Time			-1
	IST Irish Summer Time			-1
	WET Western Europe Time			0
	WEST Western Europe Summer Time			-1
	CET Central Europe Time			-1
	CEST Central Europe Summer Time			-2
	EET Eastern Europe Time			-2
	EEST Eastern Europe Summer Time			-3
	MSK Moscow Time			-3
	MSD Moscow Summer Time			-4

SUMMER TIME RULES

USA: whatever congress has decided on the spur of the moment

EU: last Sunday in March to the last Sunday in October.
The website: http://webexhibits.org/daylightsaving/ has other useful information.

A3.1 a

APPENDIX 3

TABLES THAT CONSIDER LOCATION

HORIZONTAL (AND VERTICAL DIAL) HOUR LINE ANGLES

HOUR LINE ANGLES Horizontal dial

hour angle DEGREES(ATAN(TAN(RADIANS(15*time))*SIN(RADIANS(lat))))

hour angle H = atan (sin(lat) * tan (ha))

TIME	33	34	35	36	37	38	39	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	2.04	2.10	2.15	2.21	2.26	2.31	2.36	11.75
0.50	4.10	4.21	4.32	4.42	4.53	4.63	4.74	11.50
0.75	6.18	6.35	6.51	6.67	6.83	6.98	7.14	11.25
1	8.30	8.52	8.74	8.95	9.16	9.37	9.57	11
1.25	10.47	10.75	11.02	11.28	11.55	11.80	12.06	10.75
1.50	12.71	13.04	13.36	13.68	14.00	14.31	14.61	10.50
1.75	15.03	15.42	15.79	16.16	16.53	16.89	17.24	10.25
2	17.46	17.89	18.32	18.75	19.16	19.57	19.97	10
2.25	20.00	20.49	20.97	21.44	21.91	22.36	22.81	9.75
2.50	22.68	23.22	23.76	24.28	24.79	25.29	25.78	9.50
2.75	25.53	26.12	26.70	27.27	27.82	28.37	28.89	9.25
3	28.57	29.21	29.84	30.45	31.04	31.62	32.18	9
3.25	31.84	32.52	33.19	33.83	34.46	35.07	35.66	8.75
3.50	35.37	36.08	36.78	37.45	38.11	38.74	39.36	8.50
3.75	39.18	39.93	40.64	41.34	42.01	42.66	43.28	8.25
4	43.33	44.08	44.81	45.51	46.19	46.84	47.47	8
4.25	47.84	48.59	49.31	50.00	50.67	51.31	51.92	7.75
4.50	52.75	53.47	54.16	54.83	55.46	56.07	56.65	7.50
4.75	58.07	58.74	59.38	59.99	60.57	61.13	61.66	7.25
5	63.80	64.40	64.96	65.49	66.00	66.48	66.94	7
5.25	69.94	70.42	70.87	71.30	71.71	72.10	72.46	6.75
5.50	76.41	76.75	77.07	77.38	77.66	77.93	78.18	6.50
5.75	83.14	83.31	83.48	83.64	83.78	83.92	84.05	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

NOTE: Values are degrees and tenths and hundredths of a degree. Thus latitude 39 at 1pm or 11am shows 9.57 degrees, not 9 degrees, 57 minutes. And 9.57 degrees converts to 9 degrees 34.2 minutes of arc, which is consistent with other publications.

TIME	40	42	44	45	46	48	49	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	2.41	2.51	2.61	2.65	2.70	2.79	2.83	11.75
0.50	4.84	5.03	5.23	5.32	5.41	5.59	5.67	11.50
0.75	7.29	7.58	7.87	8.01	8.14	8.41	8.54	11.25
1	9.77	10.16	10.54	10.73	10.91	11.26	11.43	11
1.25	12.31	12.80	13.27	13.50	13.72	14.16	14.37	10.75
1.50	14.91	15.49	16.05	16.32	16.59	17.11	17.36	10.50
1.75	17.59	18.26	18.91	19.22	19.53	20.13	20.41	10.25
2	20.36	21.12	21.85	22.21	22.55	23.22	23.54	10
2.25	23.24	24.09	24.90	25.29	25.67	26.41	26.76	9.75
2.50	26.25	27.18	28.06	28.48	28.90	29.69	30.08	9.50
2.75	29.41	30.40	31.35	31.80	32.25	33.09	33.50	9.25
3	32.73	33.79	34.79	35.26	35.73	36.62	37.04	9
3.25	36.24	37.34	38.38	38.88	39.36	40.28	40.71	8.75
3.50	39.95	41.09	42.15	42.66	43.15	44.08	44.53	8.50
3.75	43.89	45.04	46.11	46.62	47.11	48.04	48.48	8.25
4	48.07	49.21	50.27	50.77	51.25	52.16	52.58	8
4.25	52.50	53.61	54.63	55.11	55.57	56.43	56.84	7.75
4.50	57.20	58.24	59.19	59.64	60.07	60.87	61.24	7.50
4.75	62.16	63.10	63.96	64.36	64.74	65.45	65.78	7.25
5	67.37	68.18	68.91	69.25	69.57	70.17	70.45	7
5.25	72.81	73.44	74.02	74.29	74.54	75.02	75.23	6.75
5.50	78.43	78.87	79.27	79.45	79.63	79.95	80.10	6.50
5.75	84.18	84.41	84.61	84.70	84.79	84.96	85.04	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

TIME	50	52	54	55	56	58	59	
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	noon
0.25	2.87	2.96	3.04	3.07	3.11	3.18	3.22	11.75
0.50	5.76	5.92	6.08	6.16	6.23	6.37	6.44	11.50
0.75	8.66	8.91	9.14	9.25	9.36	9.57	9.68	11.25
1	11.60	11.92	12.23	12.38	12.52	12.80	12.94	11
1.25	14.58	14.98	15.36	15.54	15.72	16.06	16.22	10.75
1.50	17.60	18.08	18.53	18.74	18.95	19.35	19.55	10.50
1.75	20.70	21.24	21.75	22.00	22.24	22.70	22.91	10.25
2	23.86	24.46	25.04	25.31	25.58	26.09	26.33	10
2.25	27.11	27.77	28.39	28.69	28.98	29.54	29.80	9.75
2.50	30.45	31.16	31.83	32.15	32.46	33.05	33.33	9.50
2.75	33.89	34.65	35.36	35.69	36.02	36.64	36.93	9.25
3	37.45	38.24	38.97	39.32	39.66	40.30	40.60	9
3.25	41.14	41.94	42.69	43.05	43.39	44.04	44.35	8.75
3.50	44.95	45.76	46.51	46.87	47.21	47.86	48.17	8.50
3.75	48.90	49.70	50.45	50.80	51.13	51.77	52.06	8.25
4	53.00	53.77	54.49	54.82	55.15	55.75	56.04	8
4.25	57.23	57.96	58.64	58.95	59.25	59.82	60.09	7.75
4.50	61.60	62.27	62.89	63.18	63.45	63.97	64.21	7.50
4.75	66.10	66.69	67.24	67.49	67.73	68.18	68.40	7.25
5	70.72	71.22	71.67	71.89	72.09	72.47	72.64	7
5.25	75.44	75.83	76.19	76.35	76.51	76.80	76.94	6.75
5.50	80.25	80.52	80.76	80.87	80.98	81.18	81.27	6.50
5.75	85.11	85.25	85.37	85.43	85.48	85.58	85.63	6.25
6	90.00	90.00	90.00	90.00	90.00	90.00	90.00	6

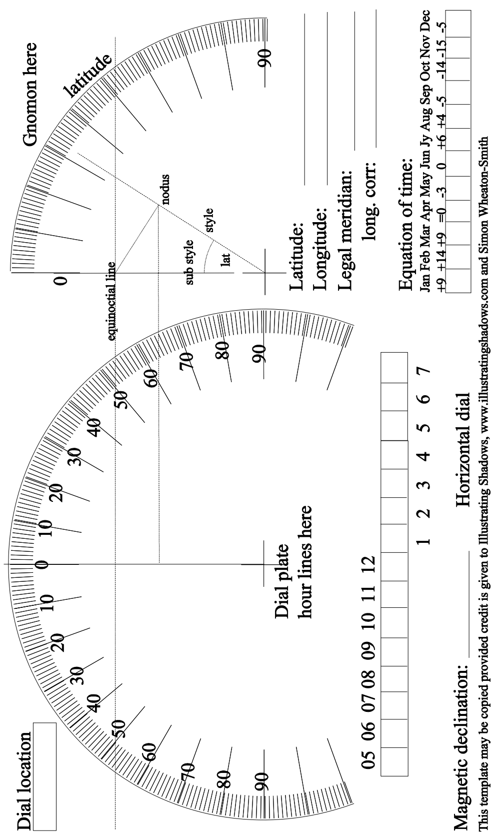
APPENDIX 9

BOOKS

ref 1 Illustrating Time's Shadow, how to make MANY Sundials for anywhere using empirical, geometric, and trigonometric methods as well as computer aided design and the spreadsheet. By Simon Wheaton-Smith

Library of Congress Control Number: 2005900674
ISBN 0-9765286-1-4
available from www.illustratingshadows.com

ref 8 Sundials And Roses Of Yesterday, Earle, Alice Morse. A somewhat nostalgic book with interesting pictures and other trivia.



SOFTWARE OF INTEREST TO THE DIALIST

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horizontal and vertical dial nomogram for hour line angles

A nomogram is an alternative to using tables, select latitude on the left, a time on the right, and read the hour line angle in the middle.