Skilcraft

STAR FINDER

MANUAL

Mike Hotka

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Precision Armillary Sphere

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STAR FINDER

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INTRODUCTION
by
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Most new products are hailed as revolutionary breakthroughs, employing the latest technological discoveries. No such claims can be made for this product. The story of this instrument, historically known as an armillary sphere, is almost as old as the history of astronomy. It dates back at least to the time of Eratosthenes (circa 250 BC) and possibly even earlier. It's among the oldest astronomical instruments ever developed and was a valuable tool of astronomers for almost 2,000 years.

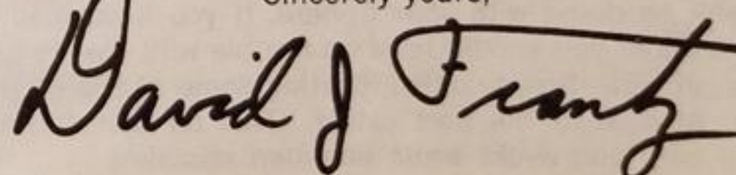
By the end of the 17th century it had fallen into disuse, not because it was no longer useful, but because astronomers now had more sophisticated instruments and apparatus at their disposal. As a result, the armillary sphere was relegated to the museums and the libraries of the wealthy (ancient armillaries were quite expensive). This was rather unfortunate, not for the professional astronomer, who already knew what the armillary sphere could show or teach him, but unfortunate for those who wanted to learn the mysteries of astronomy.

SECTION I. GENERAL INFORMATION

Few astronomical devices are as well adapted as the armillary sphere for showing, graphically, many of the basic principles of astronomy. Your Skil-Craft Star Finder is, in reality, a modern version of the ancient armillary sphere. True, it has been modernized and modified to suit today's needs, but it is essentially an armillary sphere, and as such it is not limited to just finding the stars and planets. You can also explore the fascinating field of practical astronomy and re-discover for yourself the same principles discovered by the ancient astronomers. These principles are as valid now as they were then.

With the armillary sphere you will be able to investigate the mysteries of celestial time telling, learn some of the secrets of navigation and experiment with a variety of astronomical principles. Before you use your Star Finder, browse through this book and acquaint yourself with some of its many applications and uses. And — happy star hunting.

Sincerely yours,



HOW TO USE THIS BOOK

This book is laid out in a way to give maximum enjoyment to the user of the Sphere. You can see from the table of contents that it has been divided into four main parts. There is good reason for this.

The first part contains general information about the Sphere and how the various adjustments are made. Learn the names of the four major parts and what each does. We will be referring to these parts by name in the following sections. Once you have learned the functions of these parts, you will find the Sphere quite easy to use.

The first section also discusses three kinds of time. One can hardly experiment with astronomy without having to consider time. In fact, our time is regulated and kept accurate through astronomy. Because time is so important, especially when using the Sphere, we have devoted several pages to it. Study them so you will know the relationship and how to convert from Standard Time to Local Time and vice versa. Actually, it's just a matter of simple addition and subtraction.

What we are saying is — READ SECTION I FIRST. The few minutes you spend on this section will make you feel almost like an expert when it comes to using the Sphere for the many fascinating applications and experiments to follow.

Section II shows how the Sphere is used as a star and planet finder. This will probably be one of the first things you will be doing with your Sphere. If you have read the first section, you should have no trouble with star finding. To begin with, first practice locating some of the brighter stars. Also, read the part called "Tips on Star Gazing". It will help you avoid some common mistakes.

After you have become familiar with star finding, try star identification. This is just the opposite of star finding. This, also, is a good way to learn the names of the stars and constellations. Once you have mastered this, you can move on to planet locating or finding "deep sky objects". For this you will need Section IV. In this area, the Sphere can become a valuable companion to your telescope or binoculars.

The third section is what makes your Sphere different from all other star finders. When the weather or time is not suitable for star gazing you can find much enjoyment, and learn a good deal about practical astronomy, by performing the experiments shown in this section. Some of the experiments are simple and some are designed to make you think, but none require a knowledge of mathematics, other than occasional addition or subtraction.

This section is independent of Section II and can be used first if so desired. Again, we repeat, read Section I before performing any of the experiments in Section III. Some of the experiments in this section may spark an interest in one of the fields associated with astronomy. If so, look on page 37 for suggested additional reading.

The last section, Section IV, is for reference. Located here are the various charts and tables that are referred to in the previous sections. Practically all of the additional data you might need can be found in this section.

The last page of this section (the inside back cover) is actually an astronomical instrument in itself; The Sun Quadrant. It is used for some of the experiments in Section III. Follow the directions for its use and it will give quite accurate results.

PARTS OF THE STAR FINDER

Your star finder is, in reality, an astronomical instrument called an armillary sphere. This has always been a rather impressive instrument and perhaps even a little mysterious. However, there's no mystery about it. It's simply a scale model of the universe; not the universe as we know it today but, instead, a model of the old Ptolemic universe. This was the universe as understood by most ancient people, even through the Middle Ages.

This universe was imagined to consist of an immense, hollow crystal sphere — the celestial sphere — with the earth in the center. All the heavenly bodies were believed to be attached to, or to move about, the surface of that sphere. The whole sphere rotated daily about the stationary earth. The ancient astronomers had elaborate explanations as to why certain bodies, like the sun and moon, moved differently from other bodies. However, we needn't go into that.

Of course we know now that this is not the way the universe is arranged. But strangely enough, the old Ptlolemic universe is far from obsolete. It's still used by astronomers and navigators to solve many problems in practical astronomy. Now they refer to it as "apparent motion"; the sun, moon and stars "appear" to revolve around the earth. As astronomers know, this is a handy way to visualize the universe when studying the motions of the heavenly bodies. It's this "apparent" motion that the armillary sphere shows us.

There are four major parts to the Sphere. Once you learn what they do, the Sphere becomes quite simple to us. Let's start with the two rings first. These represent the boundaries of the celestial sphere; that imaginary

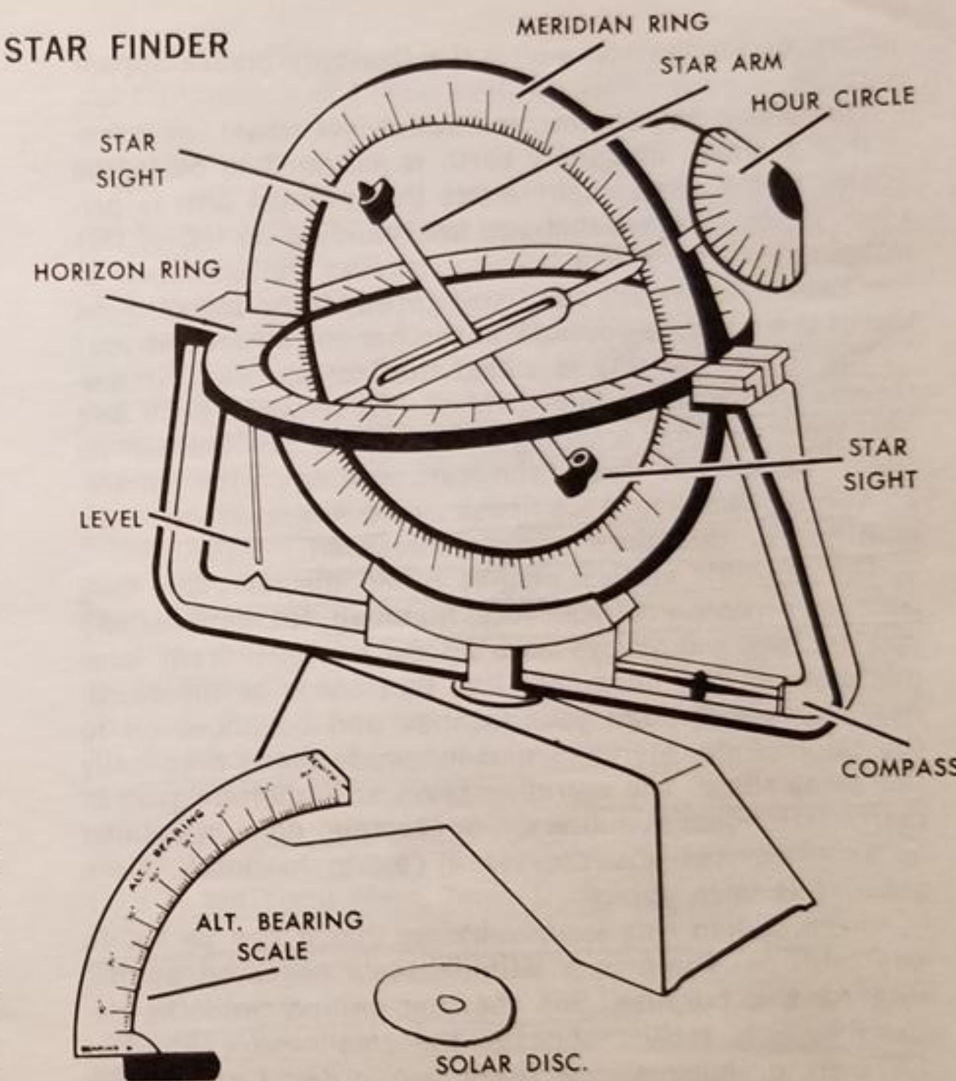


Fig. 1 Star Finder and accessories

sphere of Ptolemy on which the heavenly bodies appear to move.

One thing not shown, and which you must visualize, is that a small, imaginary earth is assumed to be in the center of the rings, right where the movable arm is pivoted. If you imagine that you are standing on top of this imaginary earth, it will help to visualize the operation of the Sphere. After all, don't you appear to be standing on top of the earth as you look at the horizon all around you?

The horizontal ring is called the Horizon Ring. It represents the horizon; that dividing line between earth and sky. We know that anything below the horizon can not be seen. The same is true of the Horizon Ring on the Sphere. This ring also has a compass scale engraved on it so bearings or directions can be measured.

The movable vertical ring is called the Meridian Ring because it represents your local meridian. No matter where you are, you will always have a local meridian. Your local meridian is that imaginary line that starts at the North Pole, passes through your location and continues on to the South Pole. Meridian and longitude mean practically the same thing. The meridian plays an important part in many astronomical matters. For example, noon is defined as the time the sun crosses a certain meridian. More about this later, though.

The meridian ring is movable so that it can be set to any latitude. There is a latitude scale engraved on the ring for this purpose. Slip the ring around until the desired latitude is just opposite the small arrow (marked LAT) on the horizon ring. If you are in doubt about your latitude, look it up on a map. In all of the applications and experiments shown, it is important that the Sphere be set for the proper latitude. You won't get the right answers unless you do.

The Meridian Ring also contains the other two major parts of the Sphere: the Star Arm and the Hour Circle. The Star Arm is pointed, somewhat like an arrow, and is pivoted in the center so that it can be set to various positions. It can also be rotated by turning the hour circle. The important part of the Star Arm is the very tip of the pointed end. This represents the celestial body being studied, whether it be the sun, the moon or a star. Even though it's called a Star Arm, it can represent any of these celestial bodies.

Practically all the applications and experiments with the Sphere require that the Star Arm be set to a certain declination. Although we'll discuss declination in the next section, the actual setting of the Star Arm is easy. The meridian ring has a set of scales engraved on it: one for North declination and one for South declination. Let's say that a certain experiment calls for setting the Star Arm to 35° North declination. Simply move the Star Arm directly under the declination scales so that the tip is pointing to the 35° mark on the North declination scale. Once you have set the Star Arm to the required declination, do not touch it again unless you want to change the setting. *Rotating the Star Arm should be done only with the Hour Circle.*

The Hour Circle is the last of the four parts of the Sphere. This is what is used to move the Star Arm. So that the Star Arm can be moved to certain positions, or to show the hourly motion of a body, the Hour Circle is marked off in hours — much like a clock dial. As the Hour Circle is turned, the tip of the Star Arm traces out the path a celestial body would take across the sky. The hour circle can be turned either east or west as indicated by the arrows.

WHAT YOU SHOULD KNOW ABOUT TIME

In 1883 our country changed from a system of local time to our present system of standard time. The former system was called local time because each city and town observed its own time, which could differ from a town 50 miles away by 5 minutes or more. This continually changing time is eliminated with standard time because everyone in the same time zone observes the same time. In the continental United States there are four standard time zones, with a one hour time difference between zones.

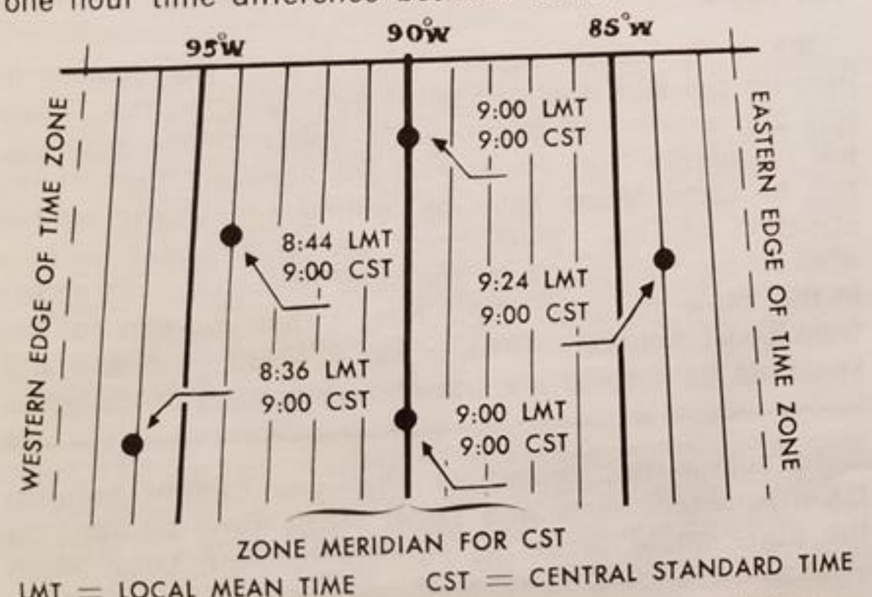


Fig. 2 Comparison of Standard time to Local time.

Surprisingly though, standard time has no real astronomical significance. It's essentially an artificial time, designed more for social and commercial convenience than for scientific applications.

But, the former local time is scientifically and astronomically correct. For this reason we will be using local time, technically called Local Mean Time and abbreviated LMT, in our use of the Sphere.

Fortunately, there is a simple relationship between Local Mean Time and standard time. You can convert from one to the other if you know how far you are from your zone meridian. Each time zone has its zone meridian. These meridians are always spaced 15° of longitude apart, starting at the Greenwich Meridian in England. The typical ones in the United States are at 75°, 90°, 105° and 120° West longitude for the Eastern, Central, Mountain and Pacific Standard Time zones, respectively.

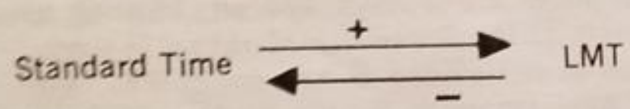
If you happen to live right on the zone meridian, your LMT will be the same as your standard time. If you don't, you will have to convert your standard time into LMT. To do this, determine your longitude from a map and then note how many degrees you are from your zone meridian. This amount, multiplied by four, is the time correction (in minutes) that must be applied to standard time to get Local Mean Time. If you are *east* of the zone meridian, *add* this correction to standard time; if west of the zone meridian, *subtract*.

For example, Chicago is in the Central Standard Time zone. The zone meridian is at 90° West longitude and Chicago is at 88° West longitude. Therefore, Chicago is 2° *east* of the zone meridian, which means that 8 minutes must be *added* to Central Standard Time to get Local

Mean Time in Chicago. If it's 10:00 PM Central Standard Time in Chicago, it's also 10:08 PM Local Mean Time in Chicago.

You can convert from LMT to standard time by reversing the above procedure. The conversion is still 4 minutes for each degree of longitude from the zone meridian. This diagram will help you to remember the conversion rule.

If you are EAST
of the zone meridian



If you are WEST
of the zone meridian

The diagram works like this. If you are west of your zone meridian and want to go from Local Mean Time to Standard Time, you must add (+) the conversion to LMT; if you want to go from Standard Time to LMT, you must subtract (−) the conversion from Standard Time. Also, don't forget that during summer most states add an hour to standard time and call it Daylight Saving Time. Local Mean Time is always figured from Standard Time.

There is another kind of local time, which pertains only to the sun, called Local Apparent Time (abbreviated LAT). It is also called sundial time, since it's the kind of time shown by many sundials. Although the apparent motion of the sun is precise and predictable, it does not move at the same rate throughout the year. In other words, it does not keep in exact step with the steady, unvarying rate of a perfect clock. At certain times of the year it runs ahead of the clock and at other times runs behind, but always, over the period of a year, averages out to exactly the same number of hours recorded by the clock. This difference between the Local Mean Time shown by a clock and the Local Apparent Time shown by a sundial is called the Equation of Time.

It's really not an equation but simply the number of minutes the sun is ahead of or behind clock time. When you are performing experiments involving the sun, you will frequently have to convert the apparent time of the sun to Local Mean Time by adding or subtracting the Equation of Time. Whether to add or subtract, and by what amount, depends on the time of the year, as shown in the table on page 38. Notice that you can convert from Local Apparent Time to Local Mean Time and vice versa; so be sure to use the correct column in the table.

To summarize, remember that you convert between Local Apparent Time and Local Mean Time by applying the Equation of Time. To convert between Local Mean Time and Standard Time, apply your longitude correction.

WHAT IS DECLINATION?

In a previous section we talked about setting the Star Arm to the appropriate declination. In astronomy the word "declination" will be coming up quite often. The best way to define it is to compare it to a term we already know. Stated in its simplest terms, declination is the celestial equivalent of latitude.

Positions on earth, as we all know, are specified by the system of lines known as latitude and longitude; with the lines of latitude running east and west and the lines of longitude running north and south, from pole to pole. With this system of lines, any position on earth can be specified. An almost identical system is used to specify the positions of the celestial bodies.

To visualize this better, think of Ptolemy's celestial sphere. Imagine that it is divided into a system of lines just like the latitude and longitude lines on a globe; only call the east-west lines "declination" and the north-south lines "right ascension". These lines can be seen on your star chart. The celestial equator is merely the projection of the earth's equator onto the celestial sphere.

Declination, like latitude, is measured in degrees and is the only thing that controls the setting of the Star Arm. Right ascension, unlike longitude, is measured in hours. We will not be using right ascension, as such, with the Sphere. We will, however, be using its hourly divisions, in many cases, to set the Hour Circle of the Sphere.

Although we consider the declination of the stars to be fixed or unchanging, this is not true of the other

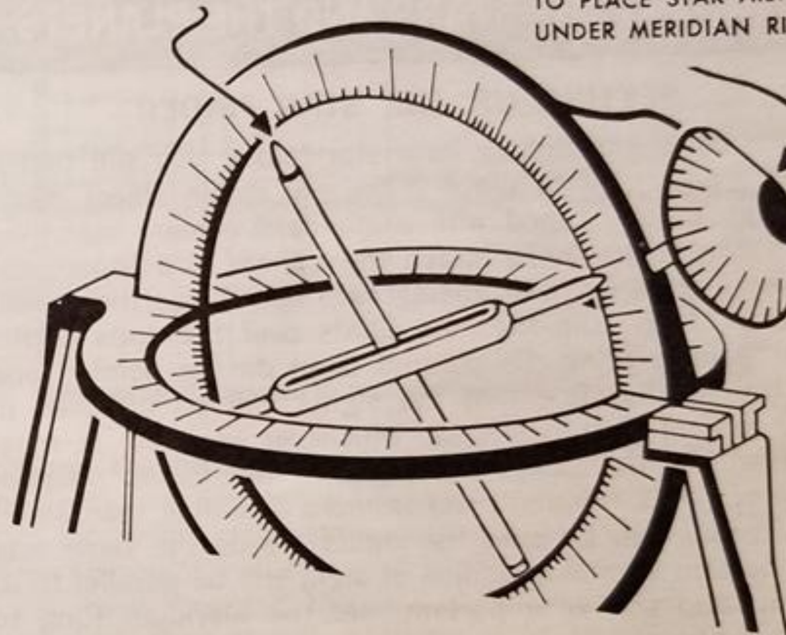


Fig. 3 Setting the STAR ARM of the Sphere.

heavenly bodies. The moon changes its declination quite rapidly, as does the sun. The planets also change their declination, but more slowly than the sun or moon. The declination of the stars can be found on the star chart. The declination of the sun for any time of the year can be found in the table on page 38 . Planet declinations will be found on the planet location charts.

SECTION II.
FINDING THE STARS AND THE PLANETS

SETTING UP THE STAR FINDER

When using the Sphere as a star finder, you will find it most convenient to place it on any stable object about 3′ high or any tripod with a standard camera mounting stud can be used. To attach the Sphere to a tripod, unscrew it from its base, taking care not to lose the rubber washer. Next, slip the star sights over the ends of the Star Arm, placing the pointed sight on the pointed end of the arm. Notice that the sights can be attached in any one of four positions, whichever you feel is most convenient. Generally, sighting *over* the forked member (the sphere's rotating axis) is more desirable than sighting through it. Be sure the sights are on the same side of the arm so that your line of sight will be parallel to it. Then, and this is important, set the Meridian Ring to your latitude.

Place the Sphere in a location that provides as clear a view of the sky as possible. When positioning the tripod, it is important that the Sphere be level and pointed in a true north-south direction. *The accuracy and success of your star finding depends upon this.* Proper leveling is indicated when the plumb level is directly over the raised tip on the frame. At the same time this is being done, the frame should be turned to point to true north. Proper north-south direction is obtained with the built-in alignment compass.

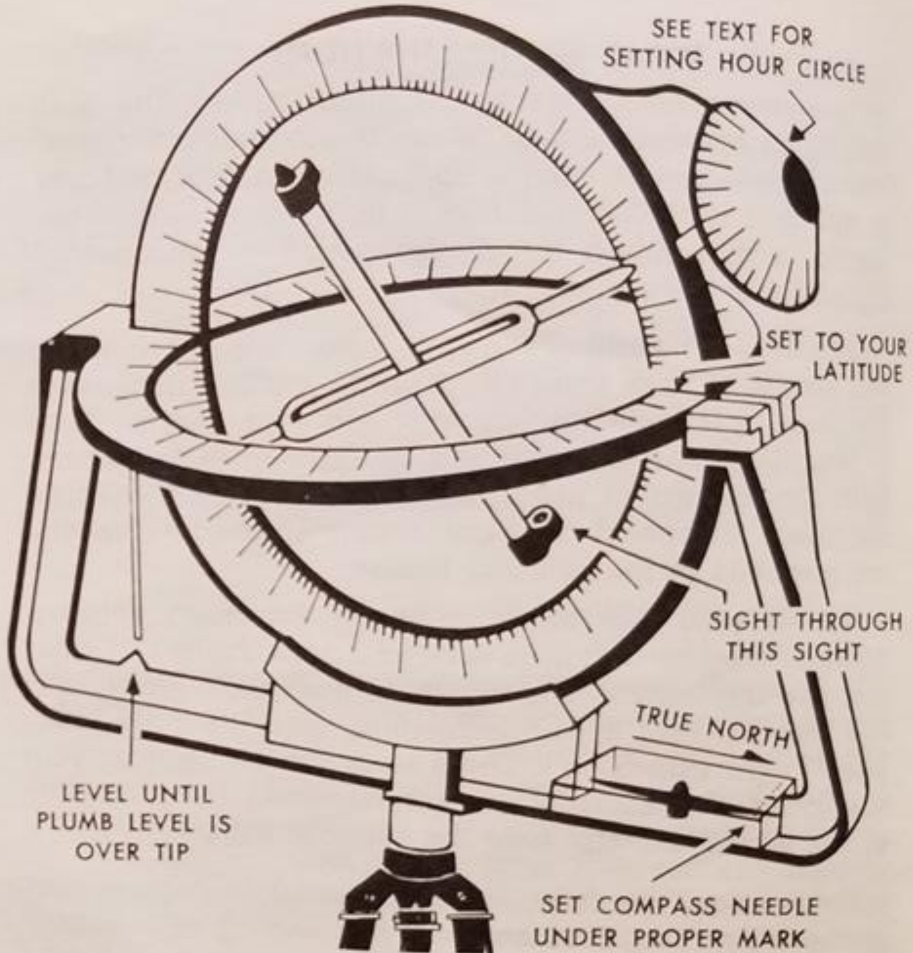


Fig. 4 Setting up as a Star Finder.

Compasses, however, point to magnetic north and not true north. Only in certain places does a compass needle point to the true north; in all other places it points somewhat east or west of true north. The amount by which a compass needle differs from true north is called magnetic variation. It is necessary to know the magnetic variation if you want to find true north from a compass. Included is a map of magnetic variation so you can determine the variation for your particular location.

You will notice on the compass cover an elongated mark, and to either side of this mark several dots. Each dot represents 5° of magnetic variation. Let's say, for example, the variation for your location is 10° East. You would set the Sphere so the compass needle is under the second dot to the east of the elongated mark. The frame of the Sphere would now be pointing in a true north-south direction, which is as it should be. If the variation is zero in your locality, simply set the needle under the elongated mark.

> To summarize, just remember these three words — *latitude, level* and *direction*.

THE STAR CHART

The Star Chart is your "directory" to the stars; it serves much the same function the telephone directory does to the telephone. It lists all the information needed to dial the Sphere in on any desired star. You will notice that it resembles a map; a set of horizontal lines for declination — the celestial equator being the middle line — and a set of vertical lines marked off in hours. Notice also that east and west appear to be reversed. This is because star charts are generally intended to be held overhead when comparing them to the heavens.

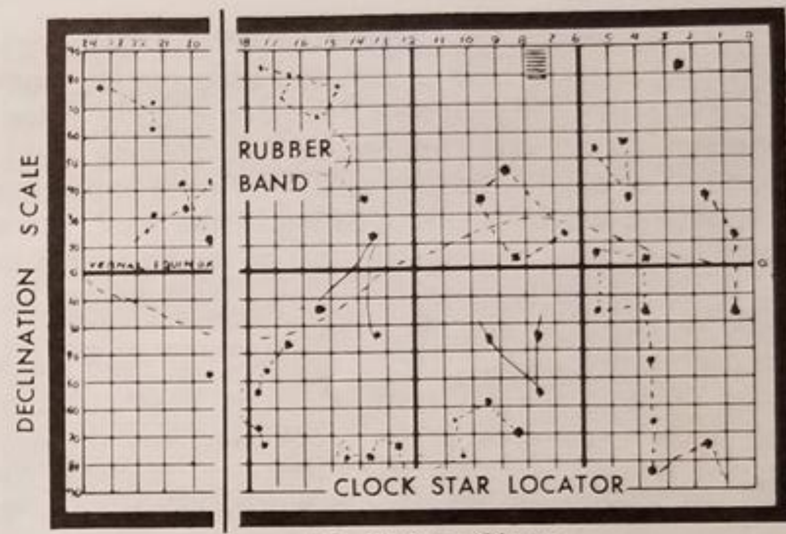


Fig. 5 Star Chart.

Along the bottom of the chart is a date scale called The Clock Star Locator. Its purpose, as the name implies, is to locate the clock star — actually, the clock star line — for any night in the year. You will find it easier to use if you have mounted the star chart on a stiff piece of cardboard. Then stretch a rubber band around the chart so that it is parallel to the vertical lines. This can serve as a marker for the clock star line. To find the clock star line for any given date, simply move the rubber band until it is over that date on the scale, making sure to keep the rubber band parallel to the vertical lines.

Star positions are identified by their declination, ie: how many degrees they are north or south of the celestial equator and by how many hours they are east or west of the clock star line. As you can see, it is important that you locate the clock star line for the current date.

THE CLOCK STAR METHOD OF STAR FINDING

Not only do the stars have a steady, hourly motion from east to west, they also appear to move slightly faster than the sun. As the stars appear each succeeding night, they seem to be slightly farther west; new ones appearing in the east and old ones disappearing in the west. Stars that were high in the summer sky are no longer visible in winter. Each season parades new star groups before us, not to be repeated for another year.

With such ever-changing stellar scenery, we need some reference point in the sky from which to base our star finding. Such a reference is the Clock Star, and the way in which it is used is called the Clock Star Method. We showed previously how, by moving the rubber band over the current date, you located the Clock Star line. Once you have done this, merely select any star along this line. This is your Clock Star for the night. Notice that a week from now, you will be using a different Clock Star.

The main purpose of the Clock Star is to teach you how to find stars — not just the Clock Star, but all stars. After a little practice, you will find that you can skip the Clock Star (but not the Clock Star line) and go directly to the star you want. But first, practice finding the Clock Star, because, if you can find the Clock Star, you can find any other star . . . or planet . . . or galaxy.

FINDING THE CLOCK STAR

Besides your Sphere and Star Chart, the only other thing you need is a watch. For best results, set it to your Local Mean Time as described on page 7. We'll assume that the Sphere has been properly leveled and pointed north and you have located the Clock Star line for the current date. From along this line select any star you wish and note its declination; that is, how many degrees it is above or below the celestial equator. The declination scale is along both the east and west edges of the chart.

Let's say, for example, that the current date is April 26. You might select Arcturus as your Clock Star. From the declination scale you find that its declination is approximately 20° North. Without disturbing the position of the Sphere, move the Star Arm so it is under the Meridian Ring and set it to 20° North declination. Then turn the Hour Circle until its hour reading agrees with your watch. If you look through the star sights, you will be looking at Arcturus.

FINDING ANY OTHER STAR

Now that you have learned to find the Clock Star, finding any other star is just one additional step. Assuming it is still April 26, let's say you want to find Spica. From the Star Chart you find that its declination is 11° South and that it is about one "hour" west of the Clock Star Line.

First set the Star Arm to 11° South declination and then set the hour circle so it agrees with your local time. So far, it's the same procedure as for the Clock Star. But remember that Spica is about one hour west of the Clock Star Line. So — turn the hour circle one hour towards the west. The star sights should now be pointing at Spica.

Let's try for another star, such as Altair. The star chart gives its location as 9° North declination and 5½ hours east of the Clock Star Line. Set the star arm to 9° North declination and set the hour circle to your local time —

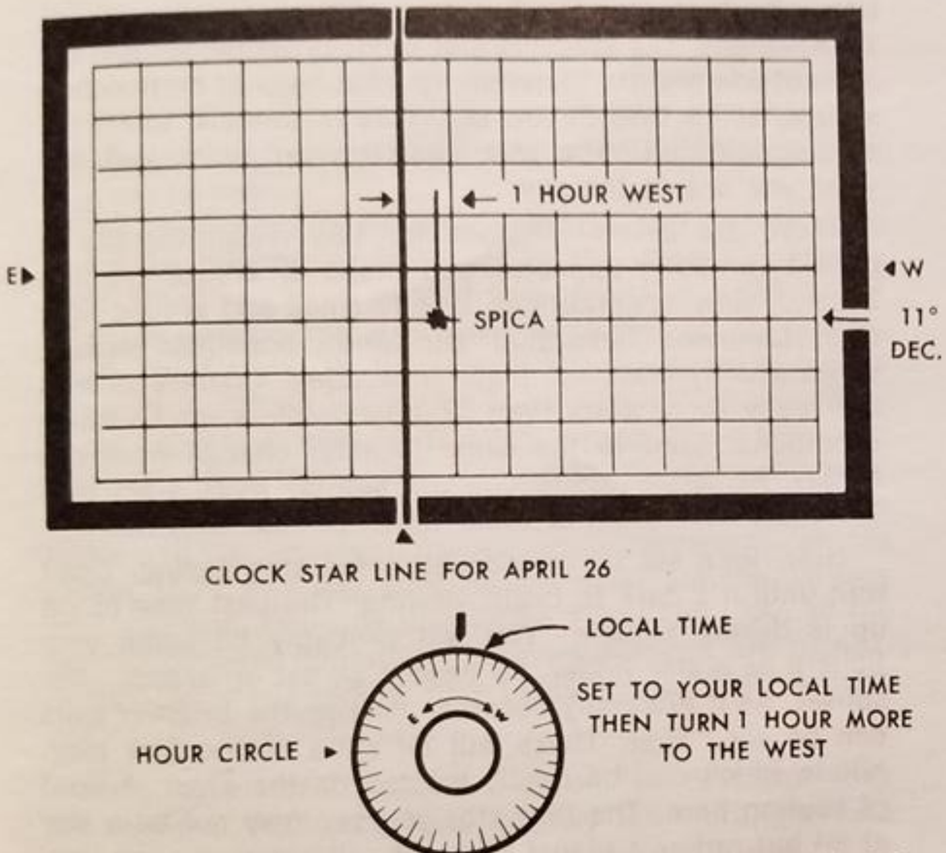


Fig. 6 Star Map and Sphere (showing setting of Hour Circle)

the same procedure as before. Now turn the Hour Circle eastward 5½ hours. The star sights should be lined up with Altair. However, if it's too early in the evening, the star arm may be pointing below the horizon. What does this mean? Simply that Altair has not risen yet; it's still below the horizon. Try again in a few hours.

FINDING THE PLANETS AND OTHER SKY OBJECTS

Planet finding follows the same procedure as star finding. The difference is that planet positions are not shown on the star chart. However, if you can plot a particular planet's position, it can be located just as if it were a star.

Planet positions cannot be permanently drawn on the Star Chart because planets are continually changing their positions among the stars. To try to show planet positions for the next several years directly on the Star Chart would clutter the chart and make it difficult to use. To avoid this, separate charts — one or more for each of the visible planets — are included with this unit. These charts show a particular planet's position for any date for the next several years.

To transpose a planet's position from these charts to the star chart, simply note its declination and hour position (right ascension), for the date selected, and make a pencil mark at the corresponding location on the Star Chart. Then, treat that mark just as you would another star and set the Sphere accordingly. Exactly the same procedure is used when locating "deep sky objects", such as those listed on the insert.

The planet location charts sometimes show what appears to be a backing up (called retrograde motion) of the various planets. This is strictly an apparent change in direction and not a real change. The planets never stop and back up in their orbits around the sun. The effect is caused by the relative motions of the planet and our earth, as seen against the background of the stars. This apparent change in direction was one of the most baffling phenomenons that confronted the ancient astronomer.

STAR IDENTIFICATION

So far we have considered the method of locating stars selected from the Star Chart. Sometimes, though, we will want to reverse this procedure and determine ". . . the name of that bright star over there." This is star identification; and, as we have said, this is just the reverse of the star finding procedure.

For this application, the Sphere is set up the same as for star finding — that is, it must be level, pointed north and set for latitude. Line up the star sights on the star to be identified and note the reading on the Hour Circle. Next, turn the Hour Circle until the Star Arm is directly under the Meridian Ring and note the declination setting. This is the declination of the unknown star. Then set the Hour Circle to your local time. Count the number of hours between your local time setting and the original position. This is the distance, in hours, the unknown star is from the Clock Star Line. Also, decide whether the star is east or west of the Clock Star Line.

Knowing the star's declination and distance from the Clock Star Line, it's a simple matter to locate it on the Star Chart. You probably won't get exact registration but you should be close enough that there is little doubt as to the identity of the star. Don't confuse a star with a planet. See the next section for star gazing tips.

TIPS ON STAR GAZING

Star gazing can be either easy or difficult, depending on how you go about it. Since easy things are usually more fun than difficult things, let's do it the easy way. The usual tendency for the beginner is to: (1) wait until it's dark outside, (2) grab his star chart or handbook and (3) run outside and try to match up what he sees on the chart with what he sees in the sky. This is where it starts becoming difficult. The star charts never quite look like what you see in the sky.

There are several reasons for this. First, the sky is curved (or so it appears) and maps or charts are flat. Second, viewing conditions, due to smog and ground light (that luminous haze that surrounds populated areas), varies greatly from one place to another. Country viewers see many more stars than do city dwellers, and viewing conditions, even in the same locality, change from day to day. At certain times you will see far more stars than the **chart** shows and at other times considerably less.

Now, let's set up a procedure for star gazing. Don't wait until it's dark to begin viewing. The best time to set up is during twilight. You will probably be using your Sphere as a star finder, so have it all set up shortly after sunset. As it gradually becomes darker, the brighter stars can be seen first. These will be stars of the first magnitude which can be readly located on the chart. A word of caution here. The first star you see may not be a star at all but rather a planet. If so, it will not appear on your star chart unless you have first plotted it in. Planets are often as bright or brighter than the brightest star. This has frequently confused beginners because these bright objects they see are not shown on their charts.

Even if you have not plotted in the planets on your chart, the Sphere can tell you whether it is a star or planet. Follow the procedure for star identification as shown on page 14. If, after determining the location of the supposed star on the chart, there is no bright star shown (1st magnitude), then it is probably a planet. Almanacs, and even many newspapers, list the planets visible each day; sometimes telling in which constellations they can be seen.

The main purpose of the Sphere in star gazing is to locate the brighter or key stars of the various constellations. Once you have located and identified six or seven of these major stars, use them as "stepping stones" to locate other stars. By the time it is completely dark, you will have identified the major stars and will be less likely to confuse them with other stars. These other stars can then be located by merely referring to the chart. It's best, at first, to learn just the brighter stars. Once you can locate and identify these quickly, then concentrate on the fainter stars and the stars which make up the various constellations. Don't be concerned if you can't see all the fanciful patterns for which the constellations are named. Being able to see swans, fish, twins and so forth is more imagination than observation.

Many people still make a wish on the first star they see at night. While this may or may not work, the first star of the evening can be a real challenge to a star gazer. See how early you can spot it, or who in a group will be the first to see it. When the planet Venus is quite bright and in a favorable viewing position, it can be seen even before sunset if you know *just* where to look.

This is where the Sphere can help. Set the Sphere to point to where the object should be. Once you know the place at which it should appear, keep watching until you see it. It will seem to appear all at once, not gradually. Don't keep looking through the star sights; just sight through them to locate that area of the sky where the star or planet should appear.

GROUP STAR GAZING

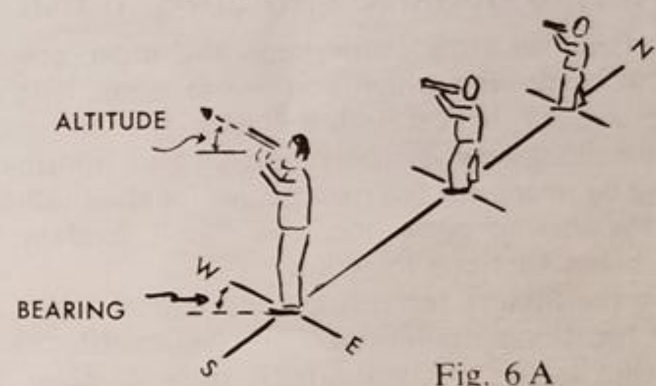


Fig. 6 A

Star gazing parties, besides being fun, are good ways to teach star identification. If there are not enough Star Finders to go around, here is how to make one serve many people. Use it to determine the altitude and bearing of the star being sought. Follow the star finding procedure on page 12 but, instead of looking through the sights, measure the altitude and bearing of the Star Arm with the Alt.-Bearing Scale as shown on page 23. By calling out the altitude and bearing, a star can be located as precisely as by looking through the star sights. To help the observers face the proper direction, draw a North-South line on the ground. After a little practice one can estimate altitude close enough for star identification.

SECTION III.
EXPERIMENTS IN ASTRONOMY

HOW TO FIND SUNRISE AND SUNSET TIMES

Sunrise and sunset time is perhaps the most common astronomical event with which you are familiar. It is also among the easiest to determine — with the Sphere, of course. Even though newspapers publish this information daily, it may be wrong for your particular location although right for the newspaper's location. We'll explain this difference in the sections to follow.

To set up the Sphere for sunrise and sunset times, you must know two things: where you are (your latitude) and where the sun is (its declination). A table of solar declinations is shown on page 38. Knowing these two things, you can determine the times of sunrise and sunset for any place in the world at any time of the year. Let's work a typical problem.

Assume that you live in Chicago, Illinois (latitude 42° North) and that it is the first day of spring (sun's declination at this time is 0°). Set the meridian ring to 42° latitude and set the Star Arm to 0° declination. Remember, the star arm must be under the meridian ring when setting declination. The pointed tip of the Star Arm will be representing the sun in this problem.

Without disturbing the settings of either the meridian ring or the Star Arm, turn the hour circle so that the tip of the Star Arm is just even with the eastern edge of the horizon ring. This is dawn. If you look at the hour circle it will show the time of sunrise, which in this case will be 6:00 AM. This is the time of sunrise on the first day of spring in latitude 42° North.

It should be pointed out that this is Local Apparent Time and not standard time. You can convert it to standard time by applying the corrections for longitude and the Equation of Time, as described in the section on time. If you do this, you will find that the sun rises in Chicago at 5:59 AM Central Standard time.

Here's another point to consider concerning the time of sunrise, or sunset, too, for that matter. The Sphere shows the theoretical time of sunrise but not the visual or apparent time of sunrise. The reason is this. Astronomers define sunrise and sunset as the instant the top edge of the sun is just touching the horizon. Because of the size of the sun, its top edge reaches the horizon about 1 to 2 minutes before its center does. All calculations with the Sphere are based on the center of the celestial body.

Also, we can actually see the sun when it is still 2 to 4 minutes below the horizon. This is due to refraction, the bending of light rays by the earth's atmosphere, which is most pronounced at the horizon. The effect of refraction becomes considerably less as the sun, or any body for that matter, rises above the horizon. Once above the horizon, and for all except the most critical observations, the effect of refraction can be ignored.

The net effect of all this is that the sun appears to rise about 3 to 5 minutes earlier, depending on latitude and declination, than the value given by the Sphere. This

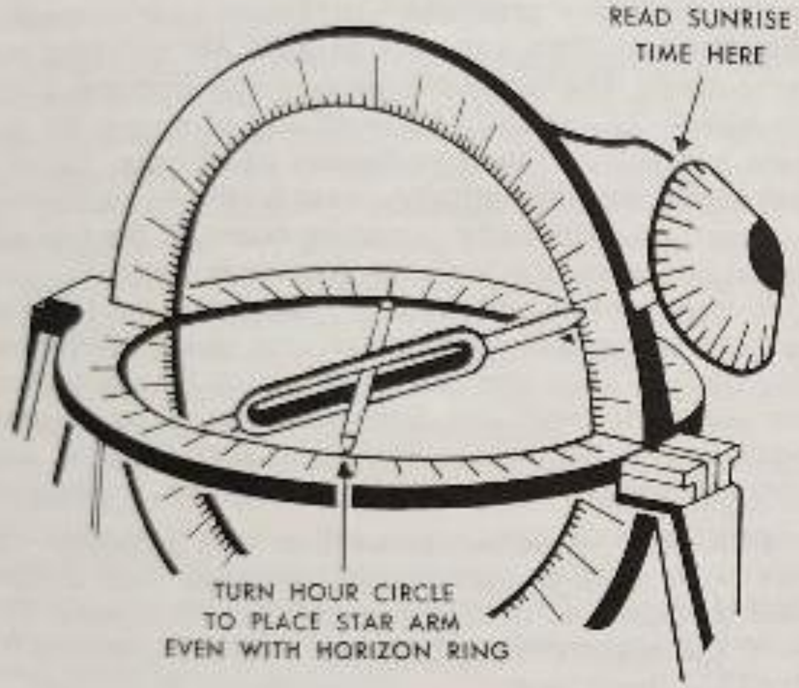


Fig. 7 Determining sunrise time.

correction is in addition to the conversion from local to standard time. In extremely high latitude this correction becomes considerably longer than 3 to 5 minutes. Applying this additional correction for refraction and the sun's diameter, we find the time of visual sunrise in our problem to be 5:56 AM CST.

Having solved the first part of the problem, let's observe the sun's path during the remainder of the day. The sun's apparent motion is westward, so turn the hour circle in a westward direction. When the Star Arm is directly under the meridian ring it is noon (local apparent time). The sun has now reached its highest point in the sky and is bearing due south. Its height above the horizon, called altitude, can be determined by counting the number of degrees between the tip of the star arm and the southern horizon. We'll be making use of altitude later on.

If we continue to turn the Hour Circle westward this brings us to the time of sunset. By looking at the hour circle just as the tip of the star arm is crossing the western horizon we can determine the time of sunset, which, in this problem, will be 6:00 PM local apparent time. Again, this is the theoretical time. Visual time of sunset would be 3 to 5 minutes later than this for the same reasons given before.

Now, let's take a look at what we have learned about the sun's motion as seen in Chicago on March 21. The sun rose at 6:00 AM (ignoring corrections), crossed Chicago's meridian at 12:00 noon, at which time it reached its greatest altitude of 48 degrees above the horizon, and then set at 6:00 PM. Notice that the period from sunrise to noon is the same as the period from noon to sunset. This symmetry of motion is true of all celestial bodies. The length of day is the sum of these two periods.

By this time you should be ready to do a few experiments on your own. For a starter, repeat the first problem, keeping the latitude at 42°, but changing the date to the first day of summer. The sun's declination is 23½° North at this time. Remember, the Star Arm must be under the scales of the meridian ring when setting declination.

If you have properly set up the Sphere you should get approximately 4:30 AM for sunrise and 7:30 PM for sunset, local apparent times. If you are within 10 or 15 minutes of these times, you are using the Sphere correctly. The noontime altitude should be 71½°.

In the following experiments you will learn some fascinating things about the behavior and motion of the sun at various places in the world and during various times of the year. Tabulate your results as you work each problem and then compare them with those given at the end of the exercise.

In each of the following problems determine the times of sunrise and sunset. Just use the times as indicated on the hour circle of the Sphere without any conversions or correction.

LATITUDE	DATE	DECLINATION
1. 45° North	March 21	0°
2. 70° North	March 21	0°
3. 20° North	March 21	0°
4. 0° North	March 21	0°
5. 0° North	June 21	N23°
6. 0° North	Dec. 21	S23°
7. 60° North	June 21	N23°
8. 80° North	June 21	N23°
9. 80° North	Oct. 20	S10°
10. 90° North	Oct. 20	S10°

In the first four problems you should have determined that the sun rises and sets at 6:00 AM and 6:00 PM, respectively. The conclusion to be drawn from this is that on March 21, actually the first day of spring, the sun rises and sets at the same time in all latitudes. The days and nights are, theoretically, equal length, hence the term — equinoxes. The same condition exists on the first day of autumn when the sun's declination is also zero.

In problems 5 and 6, which show the sun's motion as seen on or near the equator, you should have found that the sun rises and sets at the same time throughout the year. The days and nights are always equal length every day of the year. There's no such thing as long summer days or long winter nights near the equator.

Problem 7, however, shows how long a summer day can be in some of the northern countries, such as Scotland or Denmark. In this case the sun rises about 2:45 A.M. and doesn't set until about 9:15 P.M., making the day 18½ hours long.

In problem 8 we are in the "land of the mid-night sun" since we are above the arctic circle. You will notice that no matter how far you turn the Hour Circle, the sun never goes below the horizon. It dips close to the horizon at "mid-night", but that is as close as it comes.

The last two problems show the sun's path on an autumn day in high latitudes. In problem 9 the sun just reaches the horizon at noon but is below it for the rest of the time and in the last example it is dark all the time. Notice that the sun appears to move completely around the horizon but always just below it.

TWILIGHT

So far we have considered sunrises and sunsets. However, we know from experience that it does not get dark as soon as the sun drops below the horizon. There is a period of twilight that exists between the time that the sun is just below the horizon and darkness. Twilight occurs just before dawn and just after sunset and lasts for various lengths of time depending on the latitude and the time of the year. The definition of twilight (civil) is that period of time before dawn or after sunset when the sun is within 6 degrees of the horizon. During civil twilight both the horizon and brighter stars are visible.

At the equator and in tropical latitudes twilight lasts for only a short time; 20 to 30 minutes. In higher latitudes and especially during the spring and summer months twilight lasts for considerably longer periods. In fact, on the first day of summer in latitude 60° North twilight lasts almost the entire night. Near the poles, at certain times, it can last for 24 hours.

You can observe the position of the sun during twilight on your Sphere and get an approximate idea as to its duration for various latitude and declination settings.

A period of twilight can be considered to exist when the tip of the star arm is between the top edge of the horizon ring and one quarter of an inch below this edge. Notice how much farther you must turn the Hour Circle to move the star arm through this zone for the high latitudes than for the low latitudes.

The effect of longer twilight in the high latitudes brings up a curious point. If you include twilight, the north and south poles receive approximately 10% more sunlight throughout the year than does the equator. This is true in spite of the fact that the poles are in total darkness for many months of the year.

HOW STANDARD TIME AFFECTS SUNRISE AND SUNSET

Our system of standard time has a peculiar effect on sunrise and sunset time. Everyone sees these events at a different time. In the old days, when local time was the only method of time reckoning, everybody in the same latitude saw the sun rise at the same time; this is not the case with standard time. Nowadays, people on the

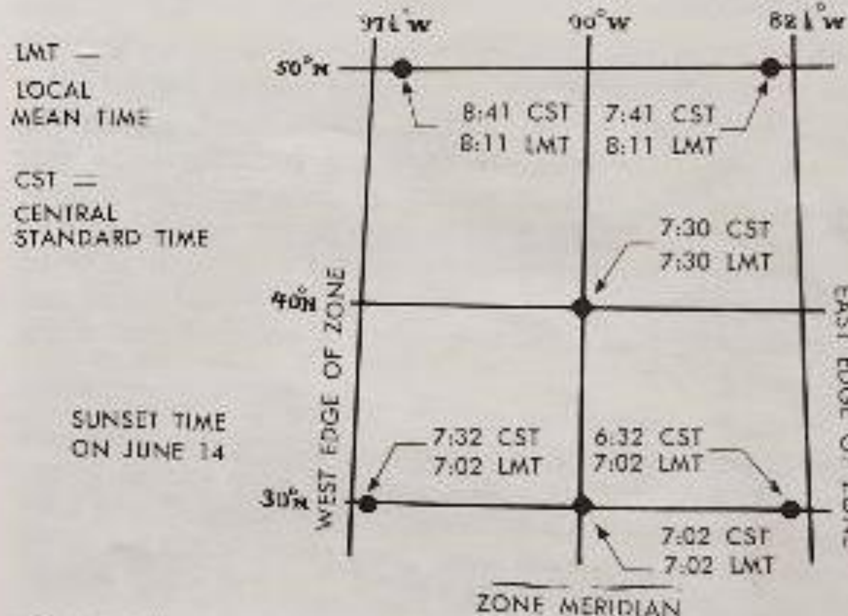


Fig. 8 Effect of Standard time on Sunrise and Sunset.

eastern edge of a time zone see the sun rise and set much earlier than those on the western edge.

The reason is fairly simple and goes like this. Time zones are generally one hour wide and everyone in the same zone observes the same time. Since the sun travels from east to west, those in the east will see it about an hour before those in the west. If there is a difference in latitude between two observers, such as one being in the northwest corner of the zone and the other being in the southeast corner, a considerable difference in the rising and setting times will occur. You can notice this yourself the next time you make a long trip within your time zone.

As you can see, it doesn't mean too much to say the sun is going to rise or set at a certain time (standard time) if you don't say where, that is, if you don't specify the latitude and longitude. Newspapers factually state that the sun will rise and set exactly at such-and-such a time, giving the time to the precise minute, yet they neglect to say where. If the newspaper covers a wide area, such as a large metropolitan newspaper, the published times can be in error by 5 minutes — or more — depending on where the reader lives.

Although it does not pertain directly to standard time, here is an interesting possibility. If, during the latter part of June, a jet airliner should take off from Denver at the time of sunset and fly to Seattle, the passengers and crew would have an unusual view. They could watch the same sunset throughout the entire flight. The sun would appear motionless on the horizon.

MEASURING TIME BY THE SUN

For this experiment, use the Solar Disc. This is the small, round white disc included with the accessory items for the Sphere. Slip it over the pointed end of the star arm and push it down so it is about two inches from the pointed end. It serves as a shadow casting surface to show when the arm is pointing directly at the sun.

It's important that the Sphere be level, pointed to true north and set for your latitude, just as it was for star

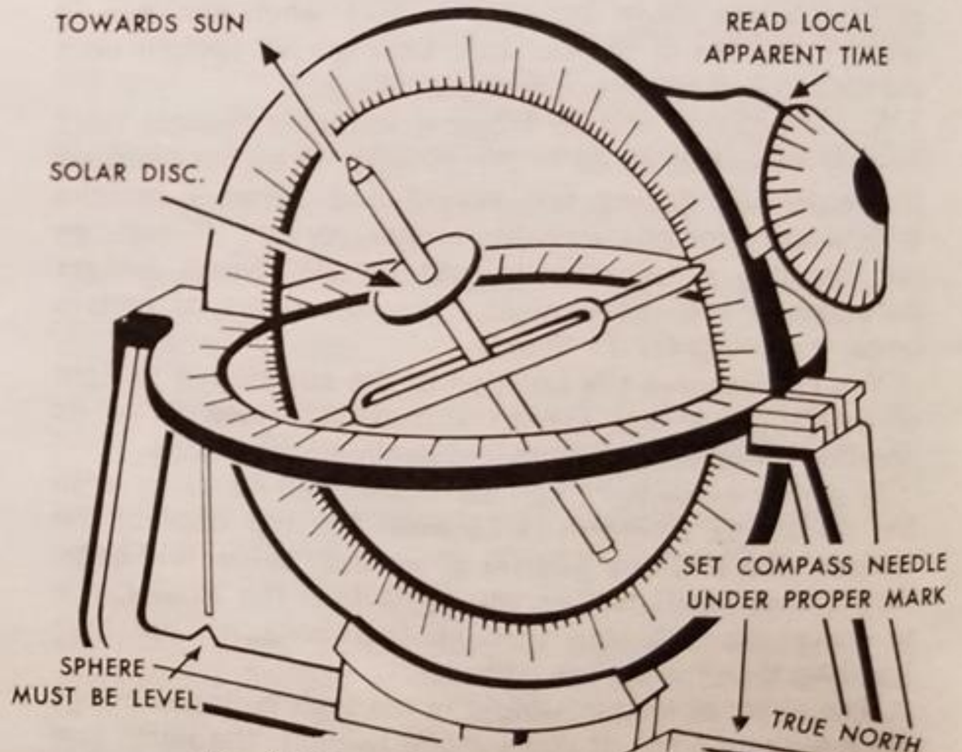


Fig. 9 Measuring time by the Sun

finding. However, it's not necessary to mount it on a tripod for this application. Look up the declination of the sun for the current date and set the star arm to this value.

Turn the Hour Circle so the Star Arm is pointing towards the sun. By watching the shadow of the Star Arm as it falls on the Solar Disc, you will be able to tell when the arm is pointing directly at the sun. When you can no longer see this shadow, the arm is aimed directly towards the sun. Now read the time shown on the Hour Circle. This will be your Local Apparent Time, which, of course, can be converted to standard time as described on page 8.

TIME BY THE STARS

For this application, and the one to follow, it's best to mount the Sphere on a tripod, just as you did for star finding. Also, attach the star sights (the solar disc is only for experiments with the sun), and again set the Sphere for your latitude, level it and point it north.

There are two ways of telling time from the stars. The first uses the Clock Star. Locate the Clock Star Line for the current date and from along this line select a star which is easily visible. Note its declination and set the star arm to this amount. Then, while sighting through the sights, turn the hour circle so you line up with your selected Clock Star. The reading on the hour circle will be your Local Mean Time. This can be converted to standard time as described previously.

It may happen, as it often does, that there is no suitable Clock Star available on a particular date. If this happens, use the second method, which involves one more step. Select a suitable star close to the Clock Star Line and note its distance, in hours, from the Line. Then, follow the same procedure as in the first method.

To the time shown on the Hour Circle, you must add or subtract the hourly distance the star is from the Clock Star Line. Add if the star is east of the Line, or subtract if it is west of the Line. For example, if the Hour Circle shows a reading of 8:15 and your star is 1½ hours east of the Line, the Local Mean Time would be 9:45 PM.

TIME BY THE MOON

The moon can and has been used for time telling, although it never achieved great popularity in this respect, mainly, because it's not always available and secondly, because its relation to solar time is not commonly known. However, for our purpose, a simple time relationship can be established which makes time telling from the moon an easy matter.

The moon, as you know, goes through a series of phases following a regular pattern; new moon to first quarter, first quarter to full moon and so on. These phases tell how many hours the moon is from the sun, or in other words, how many hours must be added to moon time to get solar time. The whole secret is to accurately judge the proper phase. The closer you judge the phase, the closer you can tell time.

During the moon's 28 day cycle it goes through four major phases, each taking about 7 days. The first phase is from new moon (which can't be seen) to first quarter. At first quarter the moon is a semi-circle and is 6 hours behind the sun. Seven days later, at full moon, it is 12 hours behind the sun and at third quarter it is 18 hours behind the sun. By the time of new moon it is 24 hours behind and the whole process starts over again.

Once you know this relationship of moon phases to hours from the sun, you can use the moon for time telling — just as you did with the stars. In fact, the set-up and procedure is the same. You won't have to set the star arm to the moon's declination as this can be done when you aim the sights on the moon. When the sights are lined up, note the reading on the Hour Circle. To this reading add the number of hours the moon is from the sun, based on the phase of the moon.

The only difficult part is estimating the phase of the moon; particularly when it is between one of its major phases. Most calendars and almanacs give the dates for the four quarters, which aids in determining the proper hour correction. For in-between days, figure about 50 minutes per day for each day past one of the major phases. Don't expect the same accuracy with the moon that you had with the sun.

There have been a number of sundials that included a "moon table" to enable them to be used at night. One of the most famous of these is at Queen's College, England and has caused many people to wonder just what the secret was. Now you know.

FINDING RISING AND SETTING TIMES OF THE STARS

When amateur telescope observers plan an observing session, they usually want to know when certain stars, planets or other celestial objects will be in favorable viewing positions. As a rule-of-thumb, it's not practical to observe a celestial object for at least an hour after it has risen nor during the hour before it sets. This is because the low viewing angle accentuates air disturbances that cause poor viewing. By knowing when certain, selected objects rise and set, you can effectively plan an enjoyable evening of viewing.

To determine rising or setting time of stars, planets, etc., follow the same procedure used for sunrise and sunset times. However, there is one additional step. For example, let's say you want to find out what time the star Antares will rise on April 26. The Star Chart shows the declination of Antares to be 26° South. Set the meridian ring to your latitude and the Star Arm to 26° South declination. Turn the Hour Circle until the tip of the Star Arm is just even with the eastern horizon and note the reading on the Hour Circle. So far it's just the same as sunrise-sunset time.

However, Antares is 2¼ hours east of the Clock Star Line for this date. This means that it will rise 2¼ hours later than the time shown on the circle. This is where the additional step comes in. If the object is east of the Clock Star Line, add its hourly distance from the Line to the time shown on the Hour Circle. If it's west of the Line, subtract this amount. This method works with any celestial body that can be located, or plotted, on the chart. Remember, though, the times you get will be Local Mean Times. Convert these to standard time as shown on page 8. Setting times are determined in the same manner. Remember also that the rising time shown on the Hour Circle will be PM and the setting time will be AM.

Once you have determined the rising time, plan to wait about one hour before observing the object. A little better rule to follow is to wait until the object has risen about

10° to 15° above the horizon. The time when this occurs can easily be determined by using the Alt-Bearing Scale. Rather than note the rising time at the horizon, note the time when the object has reached an altitude of, say, 15°. This angle of viewing is generally high enough to be satisfactory.

FINDING DIRECTIONS WITH THE SPHERE

No modern sailor would think of setting sail without at least a compass and, if the voyage was to be a long one, would probably carry a full set of navigational instruments. Yet the ancient Polynesians regularly sailed over vast open stretches of the Pacific with no instruments at all. They had never heard of the compass. Neither had the early Arabian traders, who could consistently guide their caravans across the trackless deserts. Those people got their directions from the sky — from the sun and particularly from the stars. To those who know, the sun and the stars are just as good direction finders as the compass and, in some respects, even better.

If you think the sun rises directly from the East, you will be wrong 99% of the time. On only two days out of the year does the sun rise due East; all other times it rises either to the North or South of due East. The exact direction or bearing of the sun at sunrise (or sunset) can be easily determined with the Sphere.

Set the Meridian Ring to your latitude and the Star Arm to the sun's declination. Turn the Hour Circle to place the tip of the Star Arm even with the eastern horizon. The tip will now be pointing to the bearing of the sun at sunrise. The direction at sunset can be determined in a similar manner. The time of the year and the latitude

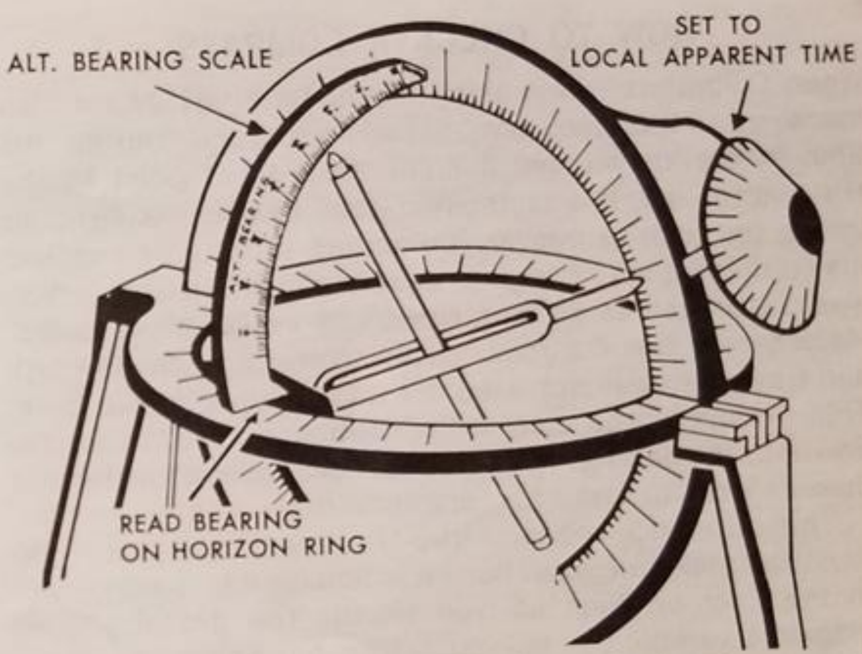


Fig. 10 Determining direction with the Sphere.

have a considerable effect on the bearing at sunrise and sunset. Try different settings on the Sphere and note the results.

Direction finding is not limited to rising and setting times alone. With the Alt.-Bearing Scale the direction of any celestial body can be measured, even if it's above the horizon. To do this set the scale on the Horizon Ring, as shown, and slide it along the ring until the vertical arc is over the tip of the Star Arm. The bearing can be read from the Horizon Ring, just at the base of the scale. When using the Alt-Bearing Scale be sure the horizontal part is inside and level with the Horizon Ring.

HOW TO CHECK A COMPASS

When Columbus was making his historic voyage he also made an important navigational discovery. During his time it was known that a compass did not point to the true north; but it was thought that this was a fixed or unvarying error. However, Columbus repeatedly checked his crude magnetic compass against the North Star (which was considered to be true North) as he sailed westward. He observed that the relationship between magnetic north and true north was not fixed but was continually changing. This discovery was also thought, at one time, to be the solution to finding longitude at sea. Unfortunately, it doesn't work too well for longitude determination.

This difference between true North and magnetic North is called magnetic variation. A compass can either point to the East or West of true North. You probably used magnetic variation when you set up the Sphere as a star finder. The variation chart shows lines of equal magnetic variation, called Isogonic lines, for the United States. But here is a strange thing. The variation is changing by a fraction of a degree each year. Over a period of years, this change adds up to an appreciable amount. Because the rate of change is known it is possible to bring a variation chart up to date — if the date the chart was printed is known.

There is still another compass error, known as deviation, to which compasses are subjected. Deviation, unlike variation, is a local effect. The best example is the disturbing effect that a ship's steel hull has on a compass. By referring to a chart, a sailor can readily determine his magnetic variation, but deviation is something he must measure for himself, since the magnetic influence of each ship is different. And, to make matters more difficult, the amount of deviation changes as the heading of the ship changes.

Total compass error (that is, the amount by which it does not point to true north) is the net result of both variation and deviation. If there are no local disturbing influences, then variation is the only thing to consider. However, you can never be sure of this. This is why sailors make a regular practice of checking compass error. By a process similar to the one we'll be using, they measure the compass bearing of the sun and then compare this to the computed true bearing of the sun. The difference between their measured bearing and their computed bearing is the total compass error.

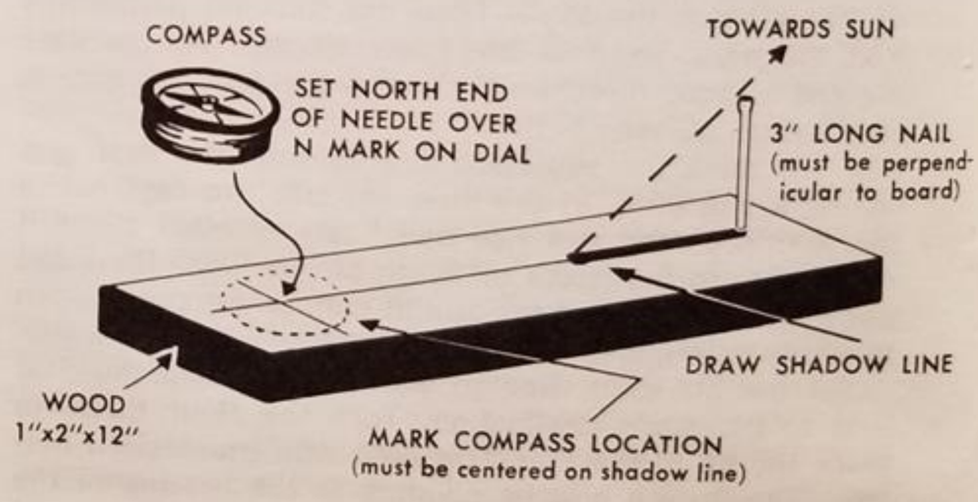


Fig. 11 Sighting bar for Compass check.

By making a sighting bar as shown in figure 11, and using an ordinary pocket compass, you can measure the total compass error for your particular location. Be sure the nail is perpendicular to the board and that the compass is centered directly over the shadow line.

Place the sighting bar on a *level* surface and turn it so the shadow of the nail falls along the shadow line. Note the exact time. Without disturbing the bar, turn the compass — but keep it centered over the line — until the north end of the needle points to the north mark on the compass scale. Record the compass bearing of the sun by noting where the shadow line intersects the compass scale.

Next, determine what the *true* bearing of the sun was at that time. If you used standard time to note the time of sighting, convert it to Local Apparent Time as described on page 8. Set up the Sphere as follows: Set the Meridian Ring to your latitude; set the Star Arm to the sun's declination for the current date, and set the Hour Circle to the Local Apparent Time of the sighting. Using the Alt.-Bearing Scale, measure the bearing of the tip of the star arm, as described previously. This is the true bearing of the sun. The difference between this bearing and the bearing measured with the compass is the total compass error.

This is the amount by which the needle must be offset from the North point in order for the North point to show true North. If the computed bearing is greater than the measured bearing, the needle offset should be to the East.

If the compass error you determined is the same as the magnetic variation shown on the variation chart you have no error due to local deviation.

However, if the total error is more than or less than that shown on the chart, the difference is caused by some local influence. This could be some large mass of iron or steel such as underground tanks or pipes, or the steel beams in buildings, or the reinforcing mesh in concrete. To see if you can notice the effect of local deviation, repeat this compass check in various locations around your neighborhood.

FINDING THE TRUE BEARING OF A BUILDING

There are several ways in which the direction a building faces can be measured; or the direction of a property line, for that matter. Using a compass is one way, but this requires a knowledge of total compass error plus a compass sufficiently large to give accurate readings. Another way, which is quite accurate, is to use the sun and a watch.

This method can be used any time the sun is available, but is most accurate between mid-morning and mid-afternoon. The idea is to note the exact time when the sun is lined up with one of the walls of the building; in other words, when the surface of a wall is pointing directly towards the sun. This is easy to do by holding the sighting bar (the same one you used before) lengthwise against the wall of the building. Be sure the nail is perpendicular and the board held level. When the shadow of the nail falls along the shadow line, note the exact time.

Convert the time to Local Apparent Time and set up the Sphere just as you did for the compass check. The bearing you read with the Alt.-Bearing Scale will be the true direction of the wall. Remember, though, the wall *faces* 90° away from this direction.

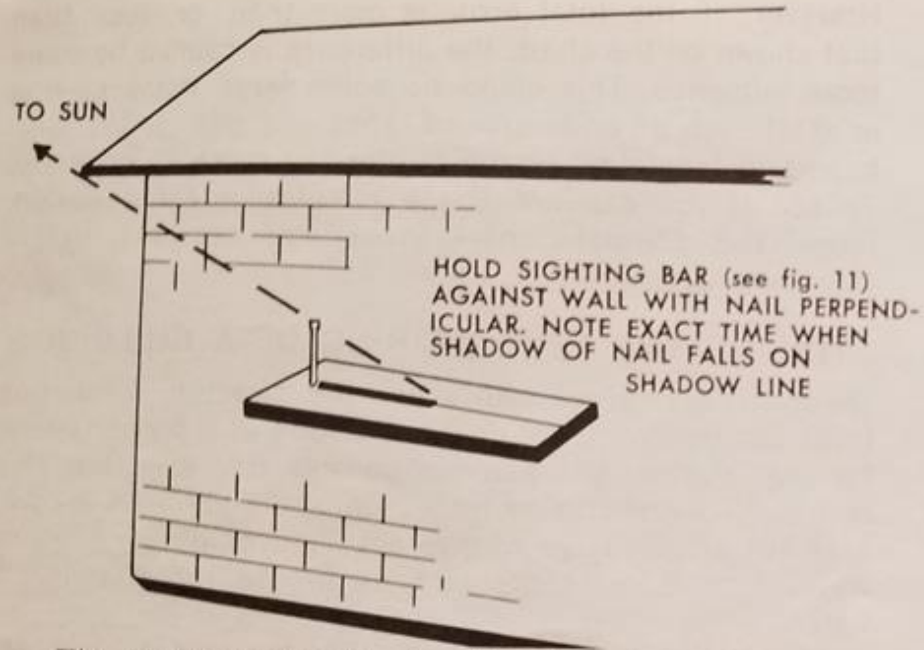


Fig. 12 Measuring the true bearing of a building.

The same procedure can be used for finding the direction of a property line. Drive a one or two foot stake into the ground — right on the property line. Scratch a line on the ground where the property line should be. This will be the shadow line for the stake. Now, simply note the Local Apparent Time when the shadow of the stake falls along the line, and compute the bearing just as before.

This technique is particularly useful if you are establishing a base line for map-making purposes. In fact, using this method and a device called a plane-table, you can make an accurate map without ever using a compass — and have it show true north.

USING THE SPHERE AS A SOLAR COMPASS

Ever hear of a non-magnetic compass? A gyro-compass is one type and a solar compass is another. In fact, the solar compass, in a disguised form, may have been in existence long before the magnetic compass. It is known that certain types of ancient sundials were self-setting; that is, they didn't need anything else to align themselves other than the sun. One particular type would actually align itself in a true north-south direction when it was set to read time.

You can use your Sphere in a manner similar to that ancient sundial and in so doing be able to determine time and direction simultaneously. Slip the Solar Disc over the end of the Star Arm and set the Star Arm to the sun's declination for the current date. Set the Meridian Ring for your latitude. Place the Sphere on a *level* surface (use the built-in level to check this) but do not use the tripod, and don't peek at the built-in compass!

The next step involves two motions. With one hand start to rotate the Hour Circle back and forth, and with the other hand, slowly rotate the base of the Sphere. Keep your eye on the Solar Disc as you do this. The object is to find the particular position of Sphere direction and Star Arm position that results in no shadow being cast on the solar disc — in other words, when the Star Arm is pointing directly at the sun.

When the Star Arm is pointing at the sun, *you will find* that the frame of the Sphere is pointing in a true north-south direction and that the hour circle is showing the Local Apparent Time. But now, let me caution you. There are two combinations of positions that will cause the Star

Arm to point directly at the sun. One of these is a false position and, of course, has no meaning. The other position is the desired true setting.

It's easy to tell which is the true position. If it's before noon the Star Arm will (or should) be on the east side of the Meridian Ring; or on the west side if it's afternoon. The only time it is difficult to determine which is which is when it is close to noon. Other than this, you should have no problem. Once the Sphere is set, the star arm should track or follow the sun throughout the rest of the day merely by turning the Hour Circle.

HOW TO FIND YOUR LATITUDE

Astronomy has played an important part in the development of navigation, which in turn helped to make possible the great explorations of the past. One of the first significant applications was the use of celestial observations for determining latitude. This lead to a method of navigation known as parallel sailing or, as it's sometimes called, "running down the latitude."

Let's say, for example, you are going to sail from Seattle to Honolulu. You would set sail from Seattle following a southerly or south-westerly course, the exact course not being too critical as long as you stay to the east of your destiantion. As you sail you would take measurements of the sun or stars until these showed that you were in the same latitude as Honolulu. At this point you would sail due west, making periodic checks to be sure you were staying on the desired latitude, until you reached your destination. As you can see, eventually you would have to reach Honolulu.

Many instruments have been devised for making those measurements, some of the early ones not unlike the sun quadrant on the back cover of this book. With the sun quadrant and Sphere you can easily determine your own latitude. Prepare the quadrant as shown, being sure to get the thread hole located accurately. To prevent tearing, place a small piece of Scotch tape over the mark before piercing the hole. Use a medium sized washer for a weight. Cut the slits for the shadow sight exactly on the lines and fold up on the dotted line. The sun quadrant is now ready.

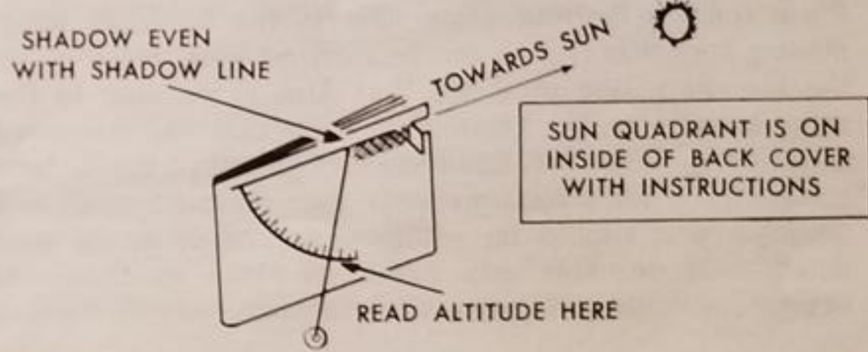


Fig. 13 Measuring the Sun's altitude with a Sun Quadrant.

Using the sun to determine latitude is commonly called a "noon sight", since it is made at the time of Local Apparent Noon. At this time the sun reaches its greatest altitude above the horizon and it's this altitude (or angle) that the sun quadrant measures. This measurement should be made within a few minutes of Local Apparent Noon for accurate latitude determination. To find out what Standard Time is for Local Apparent Noon, take 12:00 o'clock and apply the Equation of Time for the current date and your longitude correction (see page 8).

At the proper time, point the edge of the quadrant towards the sun so the shadow sight casts a long shadow across the quadrant. Hold the quadrant so the thread is just grazing, but not touching, the paper. Now, tilt the quadrant until the top edge of the shadow is just even with the Shadow Line. When the shadow is aligned, note the degree reading under the thread. This is the sun's altitude.

Next, set the Star Arm of the Sphere to correspond to the sun's declination. Leave it under the Meridian Ring. Place the Alt.-Bearing scale next to the Meridian Ring, making sure it is resting on the Horizon Ring. Now, rotate the Meridian Ring until the Star Arm is pointing to the same altitude on the Alt-Bearing scale that you measured with the sun quadrant. Read the latitude off of the latitude scale. If you were accurate with your measurements and settings, you should be within a degree or so of your actual latitude. This was about as close as the early navigators could determine their latitude.

HOW TO FIND YOUR LONGITUDE

While finding latitude was known early, a practical way of determining longitude had to wait until an accurate, sea-going clock was developed; one which would not vary more than a few minutes during a 6 weeks ocean voyage. Building such a clock was the lifelong task of John Harrison, an 18th century English carpenter. For his successful years of toiling he received his country's promised reward of £20,000 — although it took the personal intervention of the king of England before final payment was made.

Why is a clock so important for finding longitude? Because longitude and time are so closely related as to be practically synonymous with each other. If you know the difference in time between two places you, in effect, know the difference in longitude between those two places. If a clock is set to keep the time of some known place, such as the Greenwich Meridian, (0° longitude), you need only to compare it with your local time to find your longitude. Just remember, for each hour's difference in time, there is a 15° difference in longitude.

How do you find your local time? With a sundial! Or anything else that will measure local time. Although navigators don't actually use a sundial, they accomplish the same thing with a sextant. That is, they determine their local time by measuring the altitude of the sun. This method of finding longitude is called the "time sight method". Instead of a sextant, you can use the sun quadrant to measure the altitude of the sun and then, with the Sphere, convert this measurement into local time.

For this experiment, you need a watch set to Greenwich Mean Time (abbreviated GMT). Greenwich time is equal to your Standard Time plus a certain number of hours (equivalent to your zone number). The common zone numbers for the United States are: EST +5, CST +6, MST +7 and PST +8. You will find it easier, with less chance for errors, if you use the 24 hour system instead of the AM-PM system. For example, 3:00 AM = 03 00 hours, but 3:00 PM = 15 00 hours (3 + 12 = 15). So, if it's 08 30 hours Central Standard Time, it's 14 30 Greenwich Mean Time (08 30 + 6 00 hours = 14 30).

The best time to make a "time sight" is early morning or late afternoon, when the sun is bearing about due east

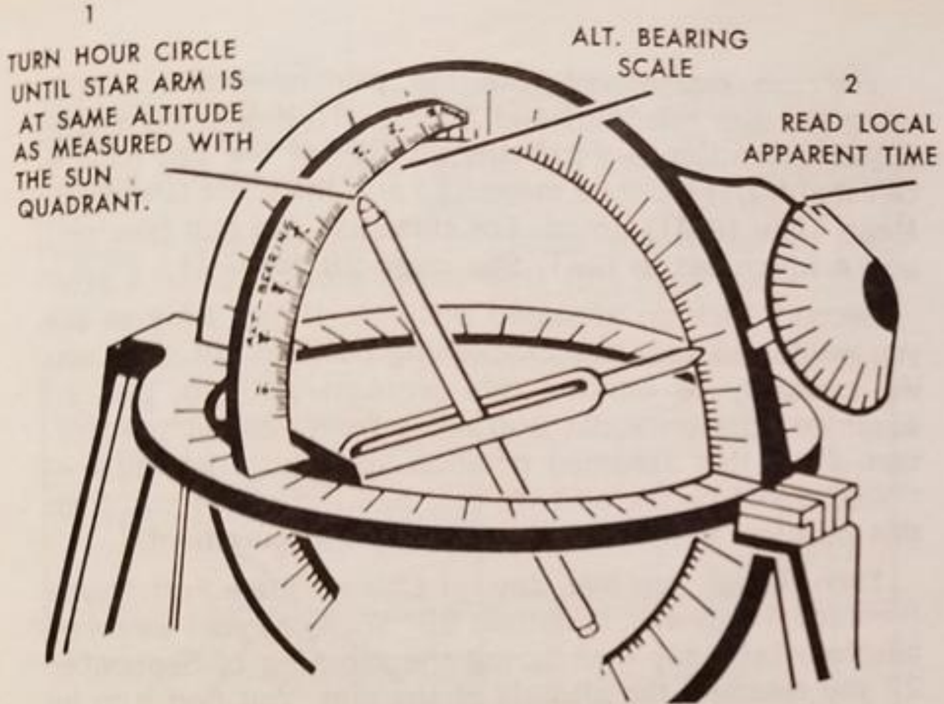


Fig. 14 Determining time from Sun's altitude.

or due west. Time sights made within 3 hours of noon are less accurate. To make a time sight all you do is measure the altitude of the sun with the quadrant and note the GMT at the time of measurement.

Convert this altitude measurment into Local Apparent Time using the Sphere as follows: Set the Meridian Ring to your latitude and the Star Arm to the sun's declination for the current date. Place the Alt.-Bearing scale on the Sphere and then rotate the Hour Circle towards the east or west (depending on the direction of the sun) until the tip of the Star Arm shows the same altitude as measured with the Quadrant.

When the Star Arm is at the proper altitude, read the Local Apparent Time directly from the Hour Circle, adding 12 hours if it's an afternoon sight. Change this to Local Mean Time by applying the Equation of Time. Your longitude, in terms of time, is the difference between your Local Mean Time and Greenwich Mean Time.

This can be converted to degrees by remembering there are 15° of longitude for each one hour difference in time or 1° for each 4 minutes. For instance, if your time difference was 5 hours and 40 minutes, your longitude would be 5 x 15° plus 10° or 75° + 10° = 85°. There is seldom any question as to whether you are east or west of the Greenwich Meridian.

THE LINE OF POSITION METHOD

The Line of Position method is a more modern approach to navigation than the two previous methods. However, its origin goes back over 130 years; back to a morning on December 17, 1837 when an American shipmaster, Captain Thomas H. Sumner, fought to save his ship and crew.

Captain Sumner was in trouble. He didn't know where he was, exactly, except that he was in dangerous waters. The sky was thick and overcast and the weather was ". . . boisterous, with heavy gales," as Sumner described it. The ship was struggling under short canvas. He was attempting to navigate through St. George's channel, between Ireland and England, with its treacherous rocks off the Coast of Wales. His last known position was three days old and his present dead reckoning position was a crude guess at best. At mid-morning a favorable break in the clouds allowed him to get a solitary altitude of the sun. From this he attempted to determine his longitude by the time sight method.

Since his latitude (which he needed to compute his longitude)was based on his uncertain dead reckoning, any calculated longitude would be equally doubtful. But with nothing else to go on, he made the calculation and plotted the result. Just to see what would happen, he assumed a different latitude and again calculated and plotted the results. And then, because he decided to make one more calculation, a great discovery was about to be made.

To his amazement, he found that all three positions fell on the same straight line. After studying this strange coincidence, he quickly realized its implications. Although he didn't know his exact position, he knew he must be somewhere along that line. The line, he saw, ran towards Small's Lighthouse, off the western tip of Wales. If he sailed along this line he would have to reach the lighthouse, which would then show him the safe passage through St. George's channel. This discovery, which is the basis of modern celestial navigation, became known as The Sumner Line.

The principle of the Sumner Line has been modernized into what is now called the Line of Position (abbreviated LOP). The beauty of the LOP is that it does not depend on a celestial body being in a certain, preferred position as it does with the conventional latitude or longitude methods. A LOP can be determined at any time. Also, if sights are taken on two different bodies — or the same body at two different times — two LOP's result. Where these two lines cross is the observers true position.

You can experiment with the principles of the LOP using the sun quadrant and Sphere. To determine a LOP requires two things. First, the altitude of the sun (or any celestial body) must be measured and the exact Greenwich Mean Time (GMT) noted. For this, use the sun quadrant and a watch set to GMT. See page 28 for GMT.

Second, pick an assumed position. If you were at sea you would use your dead reckoning position but since you will probably be working this problem on land, pick an assumed position about 200 miles from your actual location. From this assumed position you must determine — "What would be the altitude and bearing of the sun from **this** position at the time I made my measurement?"

Even though you live, say, in Chicago, use Fort Wayne (Latitude 41° North, longitude 85° West) as your assumed position. Let's say that during the morning of September 22 you measure the altitude of the sun. You find it to be 34½° at 15 00 GMT (your watch would be showing 3 00 hours, unless you have a 24 hour dial).

Now you must determine the altitude and bearing from your assumed position. Set the Sphere for 41° Latitude and set the Star Arm to 0° declination (the sun's declination on September 22). Next, set the hour circle to the proper position. This position is equal to the Local Apparent Time at the assumed position at the time you made your measurement. This is how it's determined.

At the time of your measurement, the sun was 3 hours west of the Greenwich meridian (15 00 hours is 3 hours past 12:00 o'clock noon). Your assumed position is 85° west of the Greenwich meridian, or, in terms of time, 5 hours and 40 minutes west of Greenwich. Therefore, the sun must be 2 hours and 40 minutes east of your assumed position. Set the Hour Circle so the Star Arm is 2 hours and 40 minutes east of the Meridian Ring (hour circle reads 9:20). But on September 22 the sun is running 7 minutes fast: this means you move the Hour Circle 7 minutes more to the west (the hour circle should now read 9:27).

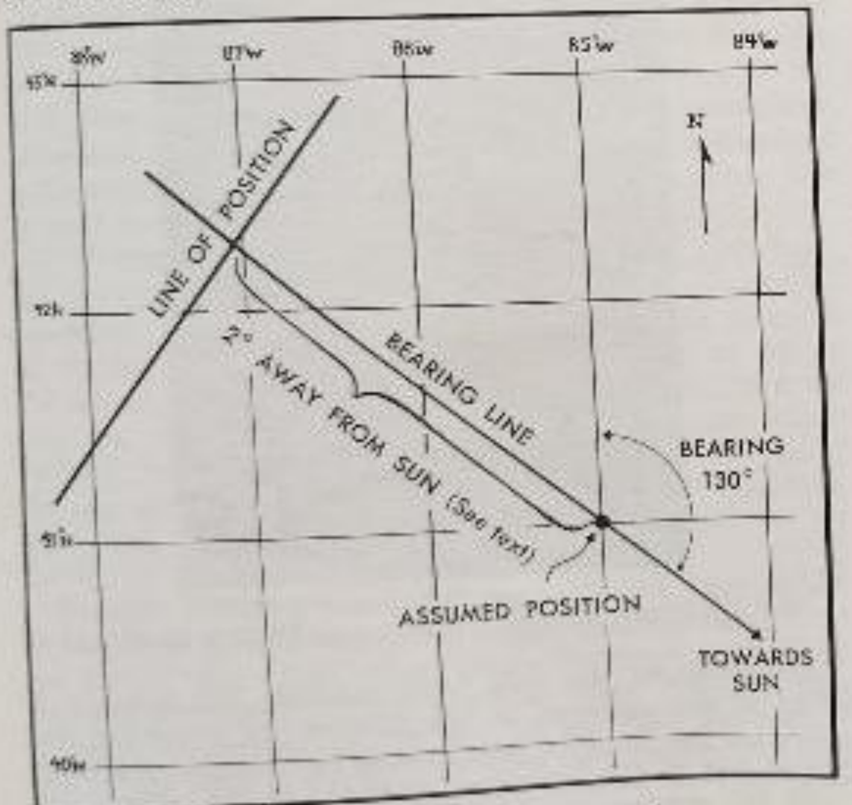


Fig. 15 Drawing the line of position.

The Sphere is now set up. Using the Alt. Bearing Scale, measure the altitude and bearing of the tip of the Star Arm. The altitude should be 36½° and the bearing 130°.

Now to plot the LOP. On a map draw a line through the assumed position having a bearing of 130°. Somewhere along this bearing line, and perpendicular to it, you will draw the actual LOP. To find out where, compare your measured altitude with your computed altitude and take the difference. In this case, it's 36½° minus 34½° or 2°. Using the latitude scale on your map, measure off a distance equal to 2° and transfer this distance to the bearing line as follows: Starting at the assumed position, measure off this distance away from the direction of the sun. Had your observed altitude been *greater* than your computed altitude, you would have laid off this distance *towards* the sun.

At the measured point, draw a line at right angles to the bearing line. This is your Line of Position. If you worked the problem correctly, you will be somewhere along this line.

ASTRONOMICAL DETECTIVE WORK

In this section we will depart from the purely practical and common-place aspects of astronomy and look at some off-beat applications. The two stories to follow are strictly fiction but are based on sound astronomical principles. Although the solution is explained for each story, before reading the answer, see how close you can come to it using the knowledge you have already gained.

THE CASE OF THE INNOCENT HEIR

Cedric Hathaway has been trapped in a web of circumstantial evidence indicating that he might have been responsible for his wealthy uncle's recent demise. Ever since the butler found the old gentleman slumped over his desk, Cedric has stoutly maintained his innocence, claiming he was over a hundred miles away when the fatal shots were fired. Hathaway is now on trial. And, in view of the strong case against him, it appears that he will not be able to enjoy his newly acquired inheritance.

His only witness, a cousin at whose home he claims to have been visiting on the day in question, has been discredited by the prosecution on the grounds that he and Hathaway were conspirators . . . especially since the cousin also receives a sizable portion of the uncle's estate. The only evidence Cedric can produce to substantiate his claim is a snapshot taken of him on front of his cousin's home on the day of the visit.

The prosecution attacks the validity of the picture as evidence. While the man in the picture, they allow, is obviously Hathaway and the house is no doubt the cousin's home, the picture could have been taken anytime. It is, therefore, no evidence at all.

"Not so," cries Cedric's attorney. Fortunately for Cedric, his attorney was also well versed in matters of practical astronomy. Knowing that his only evidence would be questioned, the attorney had taken the precaution of sending a surveyor to the cousin's home to make certain measurements. Armed with the surveyor's data and the picture he is able to prove that Cedric Hathaway was, in fact, at his cousin's home on the very hour his uncle was murdered.

Cedric is acquitted. Subsequent investigation shows the butler to be the real villain (as it always does). What was in the picture and what measurements did the surveyor take that proved Cedric's innocence? Before reading the solution, decide what you would have done. Once you learn the method, you may want to try it on a suitable snapshot of your own.

Fig. 16 Photo of Cedric Hathaway (notice shadows)

ANSWER: As you may have guessed, the solution is found in the shadows of the picture. By observing the snapshot, the surveyor was able to re-construct the position of one of the prominent shadows in the picture. He chose the shadow cast by the post next to Cedric. Having located one corner of the shadow, he ran a string up to the corner of the post which cast the shadow. The string represented a ray of sunlight and, therefore, pointed directly to where the sun had been at the moment the picture was taken.

Once the string was properly located, two measurements were taken. One measurement was to determine the direction or compass bearing of the string, which, of course, would also be the bearing of the sun at the time of the picture. Next, the angle the string made with the level ground was measured. The angle was the altitude of the sun at the moment the picture was taken. (Note: This angle could also be measured by holding the shadow line of your Sun Quadrant parallel with the string.)

With just these two measurements, altitude and bearing, the exact time and date the picture was taken can be computed. For us, the easiest way to do this is to set it up on the Sphere. Be sure the Meridian Ring is set to the latitude of the picture. Then, set the Alt.-Bearing scale over the corresponding bearing on the Horizon Ring. Holding the Alt.-Bearing scale in place, place the tip of the Star Arm under the measured altitude on the altitude scale. The Sphere is now duplicating the position of the sun at the time the picture was taken.

Without changing these settings, note the time shown on the Hour Circle. This is the Local Apparent Time when the picture was taken. Now, rotate the hour circle until the Star Arm is under the Meridian Ring. You can now read the declination of the sun on the date the picture was taken. Look in the table of solar declinations and find the date on which this declination occurs. At this point you will discover that the picture could have been taken on two different dates. Unless the picture was taken close to the summer or winter solstice, (the first day of summer or winter), the dates will generally be far enough apart that you can tell from the picture which is the probable date.

If the picture was taken during June or July (or December or January), it will be quite difficult to determine the date with any accuracy. This is because the sun's declination changes slowly during this time. In other words, the declination shows little change for several weeks.

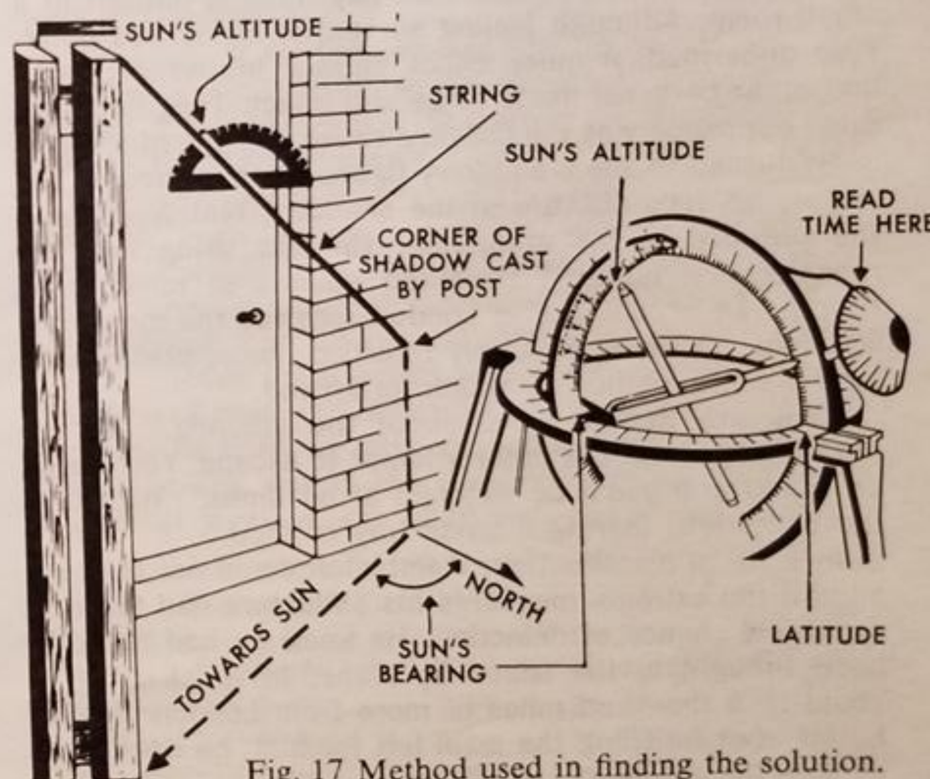


Fig. 17 Method used in finding the solution.

THE CASE OF THE KIDNAPPED BUSINESSMAN

On the evening of June 13 Reginald Wembleton, a wealthy London industrialist, was on his way to attend a meeting of the Royal Astronomical Society, of which he was a member. He never arrived. The last thing he remembers that evening is getting into his car, struggling briefly as a sweet smelling cloth was clamped over his face . . . then nothing.

He awoke sometime the next day, finding himself in a small room. Although feeling somewhat ill, he was otherwise unharmed. A quick check showed his wallet, watch and other personal items to be still intact. This, he knew, ruled out robbery as the possible cause of his predicament.

He turned to see a shadowy figure enter the room. The visitor, his face obscure in the shadows, told Wembleton the purpose of his abduction. He was being held for ransom . . . a hundred thousand pounds of ransom! As soon as an accomplice in London received the money, he was told, he would be safely returned home, presumably, by the same method by which he arrived.

"You are free to move about the grounds," his abductor told him, "but don't attempt to escape. You are on an island and you'll be watched at all times." With this, the caller left, leaving a small tray of food.

In spite of his situation, Wembleton could not help but admire the extreme measures his abductors had taken to avoid any chance of detection. He knew he had probably been brought to the island by plane, in which case he could be a thousand miles or more from London. Feeling better after finishing the meal left for him, he decided to explore the nature of his prison.

Outside the sky was clear and bright. The warmth of the sun suggested a somewhat tropical climate. He studied the various buildings comprising the villa, drawing a mental picture of what he saw should he ever have occasion to identify them in the future. He then proceeded to a small stretch of beach in front of the villa and spent the rest of the afternoon lounging on the warm sand.

Except for his earlier visitor, the only other sign of life he saw was a distant freighter, steaming slowly towards the setting sun. He was still on the beach, watching the first stars of evening appear, when he heard his captor calling for him to return to his room. Upon entering the room, he observed a cup of tea together with some biscuits. "Not much of a meal," thought Wembleton, "but better than nothing". Within minutes, the drugged tea had its effect. As he lapsed into unconsciousness, he realized the ransom must have been paid and that he was being returned to England.

He awoke some eight hours later; this time in a deserted train station. He quickly made his way to a phone to notify his family and police of his safe return. After arriving at his home, the head of the police investigating team, an Inspector Watson, was explaining the almost complete lack of clues. The inspector admitted there was virtually no chance of apprehending the kidnappers or of getting the money back.

Wembleton excused himself from the police and his family and disappeared into his study. About fifteen minutes later he reappeared, carrying a map of the North Atlantic Ocean. "I think," said Wembleton, pointing to a penciled line on the map, "you will find the island I was

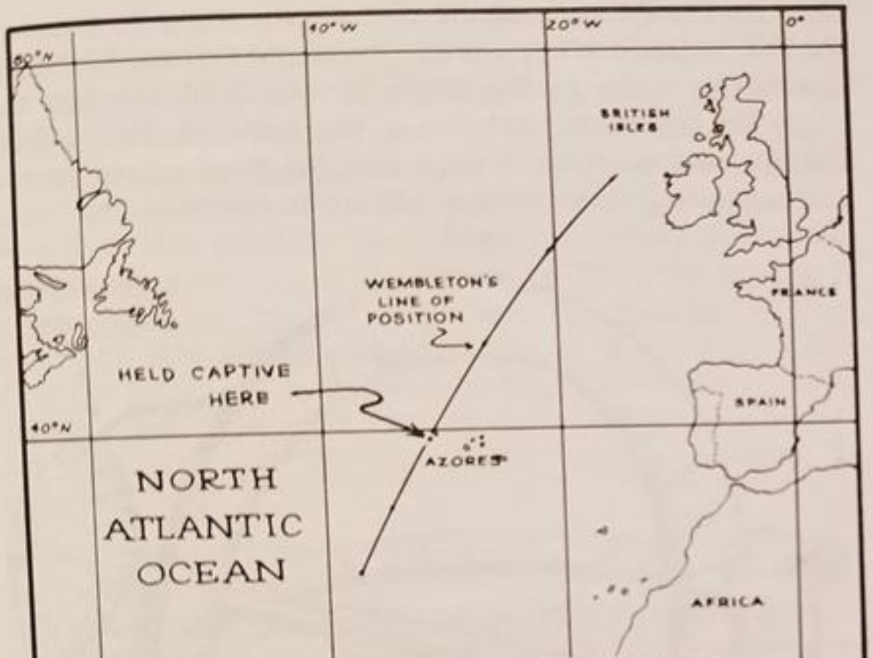


Fig. 18 NORTH ATLANTIC OCEAN

on to be somewhere along this line.'' The only two islands through which the line passed were in the Azore group. The authorities on both islands were alerted and given Wembleton's description of the villa hideout. A few hours later one of the islands radioed back that the group had been apprehended in the very act of counting the prudently marked ransom money, much to the relief of Wembleton and the amazement of Inspector Watson.

If you had been Wembleton, how would you have solved this case? If you have studied the previous sections, you will have a good clue as to how it was accomplished.

ANSWER: Wembleton made one measurement and from this was able to determine his "line of position". He simply noted the time of sunset (remember, he still had his watch) and then made a series of assumptions. The assumptions went something like this: "On June 14, I observed sunset at 9:28 by my watch (which would be set to GMT since he lived in London). **If** I was in latitude 50° North, the sun would have set at 8:06; which means I would have been 1 hour and 22 minutes or 20° 30′ west of Greenwich."

"However, **if** my latitude was 45° North, the sun would have set at 7:43; which would mean a time difference of 1 hour and 45 minutes. Therefore my longitude would have to be 26° 15′ west."

Wembleton made a series of assumptions such as these and, for each assumed latitude, determined what his longitude would have been — based on the difference in time. These are shown in the table below. He then plotted each latitude, and the corresponding longitude, on a map and connected these points with a smooth line. This was his "line of position". Although he did not know his exact location, he knew he must be somewhere along that line. Since the line was in the proximity of only two islands, his actual location was quite well pin-pointed.

Assumed Lat.	Wembleton's Watch (GMT)	Sunset LMT	Time Diff.	Longitude
50° N	9:28	8:06	1h 22m	20° 30′ W
45° N	9:28	7:43	1h 45m	26° 15′ W
40° N	9:28	7:25	2h 03m	30° 45′ W
35° N	9:28	7:11	2h 17m	34° 15′ W
30° N	9:28	6:58	2h 30m	37° 30′ W

While Wembleton obtained his sunset times from nautical tables, you can calculate the times with your Sphere. See the section on sunrise and sunset times. And while you're at it, see what would have happened to the line of position had he been abducted on September 21. Wembleton also made the statement that, had he been able to note the time of sunrise the following day, he could have determined his exact position. For a clue as to how this can be done, see page 18.

HOW TO MAKE A SUNDIAL

Ever hear of the "science of gnomonics"? Not many people have; not these days, anyway. It pertains to the design and construction of sundials. It's also been called "the art of dyalling". Sundials were perhaps the first practical astronomical instruments ever developed, even preceding the Armillary Sphere. Properly designed and constructed, a sundial can be an amazingly accurate time piece. One type, called a heliochronometer, is accurate to a few seconds.

There are three general classes of sundials, but we are going to consider only one common type — the horizontal hour angle type. This sundial has only two parts: the dial itself, which contains the hour markings and the gnomon which casts the shadow onto the dial. To get you started with your first dial, we have included a full size layout pattern on page 39. The protractor makes it easy to draw in the hour lines at just the proper angles. The question is — "What are the proper angles?"

Before you begin, here is a tip that will cut your work in half. Sundials are symmetrical. The angles of the hour lines on the PM side of the dial are the same as those on the AM side. In other words, the angle for the 11:00 AM line is the same as the angle for the 1:00 PM line; the angle for the 10:00 AM line is the same as for the 2:00 PM line and so forth. Notice that the hour values for the corresponding lines always add up to twelve.

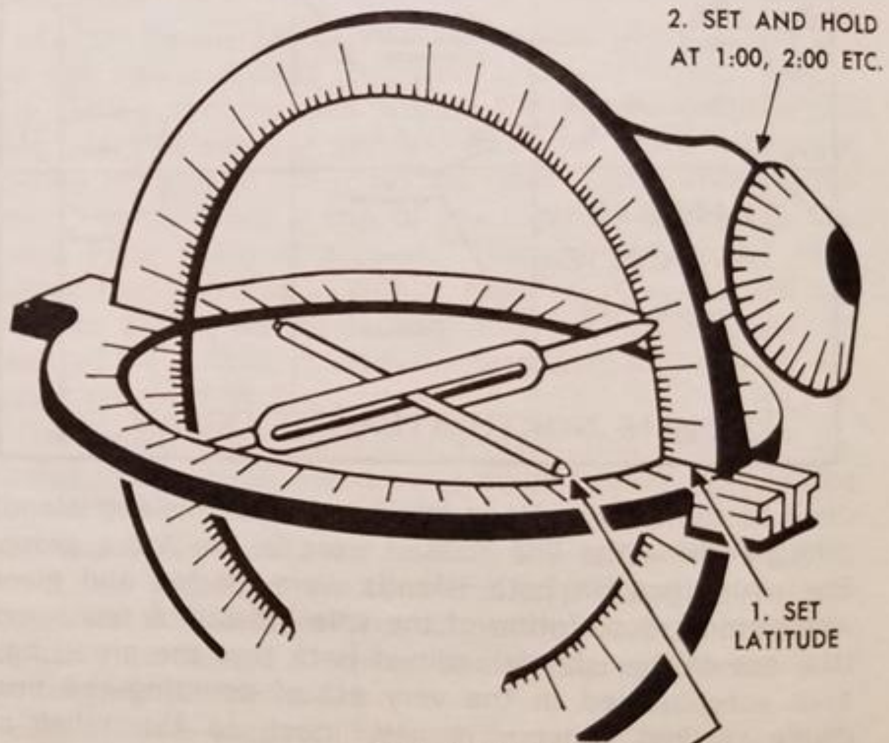


Fig. 19 Designing a Sundial

For finding the hour line angles you will need the Sphere. Set the meridian ring for the latitude in which you will use the sundial. Designing for a different latitude gives a different set of hour lines. Swing the star arm around so the tip is close to the north end of the horizon ring. Then set the hour circle to exactly 1:00 o'clock and hold it in this position so it does not move. With your other hand, gently move the tip of the star arm so that it is even with the horizon ring. Note the bearing reading where the star arm is pointing. This is the angle for the 1:00 PM hour line. It will also be the angle for the 11:00 AM hour line. Use point "A" as the starting point for all AM hour lines and "B" for all PM hour lines. Draw in these two lines.

Next, set and hold the hour circle at 2:00 o'clock and, with your other hand, bring the tip of the star arm even with the horizon ring — just as you did in the first step. Note the bearing reading where the star arm is pointing. This is the angle for the 2:00 PM – and 10:00 AM — hour line. Again, draw in these two hour lines just as you did before. Continue this procedure for each hour up to 7:00 PM and 5:00 AM. Since the 6:00 o'clock hour lines are always at 90°, these have already been drawn in.

Make the gnomon pattern by drawing a line from the gnomon point through your latitude on the scale. Extend the vertical line upwards to meet this line. Cut out both the dial pattern and gnomon pattern and paste on ⅛ inch plywood. Trim the gnomon so it is the same size as the pattern. The triangular shaped gnomon is cemented along the 12:00 o'clock line. The pointed end of the gnomon must be even with the 6:00 o'clock line. Be sure the gnomon is perpendicular to the dial while the cement is drying.

This completes your sundial. For a sundial to indicate correctly, it must be properly positioned. This means that the dial must be perfectly level and turned so the 12:00 o'clock line is pointing to true north. Careless setting of a sundial gives inaccurate results.

This sundial shows Local Apparent Time; but you should have no trouble converting it to standard time. For convenience, a condensed guide for the Equation of Time and longitude correction is printed right on the dial. Skilled sundial makers (I suppose you could call them gnomonicists) can design sundials that show standard time directly — to within a fraction of a minute.

If you would like additional information on the subjects covered in this section, here is a brief list of suggested reading.

Time and its Measurement
by H. J. Cowan — *The World Publishing Co.*

Sun dials
by Mayall and Mayall — *C. T. Branford Co.*

Brief History of the Art of Navigation
by L. A. Harding — *The William-Frederick Press*

Discover the Stars
by Johnson and Adler — *Sentinel Books Publishers, Inc.*

SECTION IV. CHARTS AND TABLES

SOLAR DECLINATION AND EQUATION OF TIME

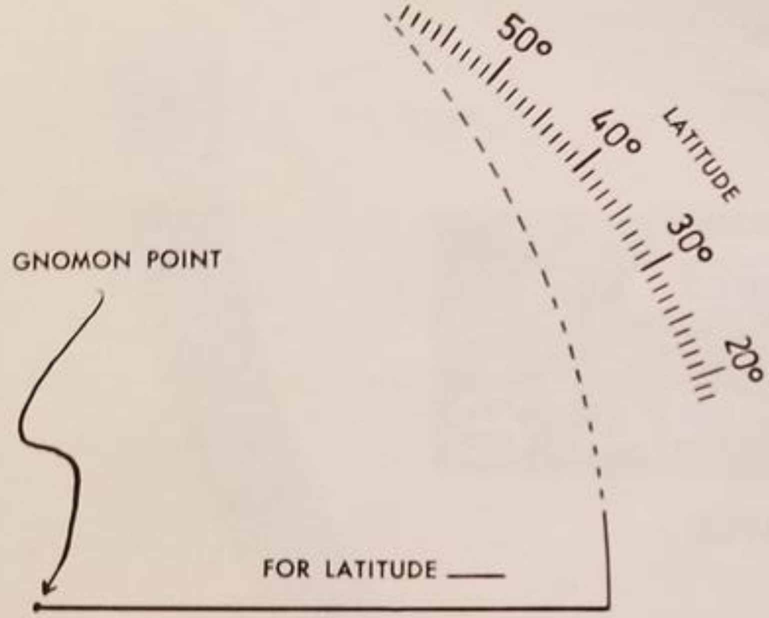
N = North S = South

Date		Sun's Declination	Equation of Time: to Convert from Apparent Time to Mean Time	Equation of Time: to Convert from Mean Time to Apparent Time
January	1	S 23°	+4	−4
	10	S 22°	+8	−8
	20	S 20°	+11	−11
February	1	S 17°	+14	−14
	10	S 14°	+14	−14
	20	S 11°	+14	−14
March	1	S 8°	+12	−12
	10	S 4°	+10	−10
	20	0	+7	−7
April	1	N 4°	+3	−3
	10	N 8°	+1	−1
	20	N 11°	−1	+1
May	1	N 15°	−3	+3
	10	N 18°	−4	+3
	20	N 20°	−4	+4
June	1	N 22°	−2	+2
	10	N 23°	−1	+1
	20	N 23½°	+1	−1

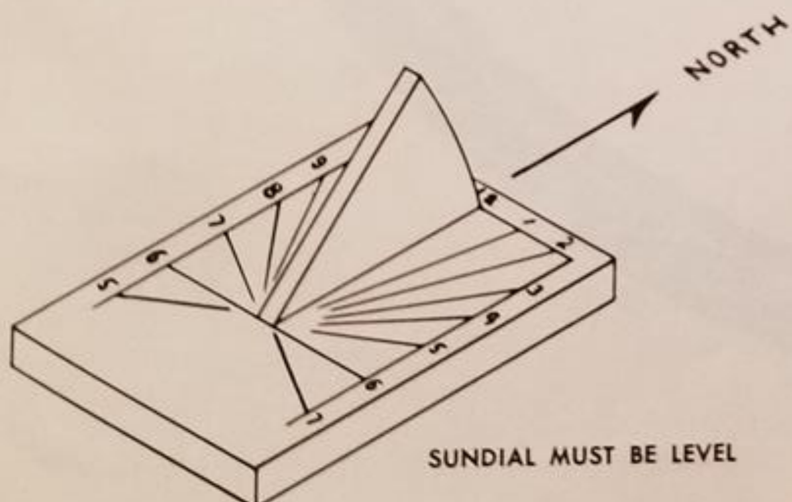
Date		Sun's Declination	Equation of Time: to Convert from Apparent Time to Mean Time	Equation of Time: to Convert from Mean Time to Apparent Time
July	1	N 23°	+4	−4
	10	N 22°	+5	−5
	20	N 21°	+6	−6
August	1	N 18°	+6	−6
	10	N 16°	+5	−5
	20	N 12°	+3	−3
September	1	N 8°	−1	+1
	10	N 5°	−4	+4
	20	N 1°	−7	+7
October	1	S 3°	−11	+11
	10	S 7°	−13	+13
	20	S 10°	−15	+15
November	1	S 14°	−16	+16
	10	S 17°	−16	+16
	20	S 20°	−14	+14
December	1	S 22°	−11	+11
	10	S 23°	−7	+7
	20	S 23½°	−3	+3

Declination: The solar declination in this table are average declinations. For more specific values, refer to the Nautical Almanac or the Old Farmers Almanac for the current year. Values for in-between dates can be estimated to the nearest degree.

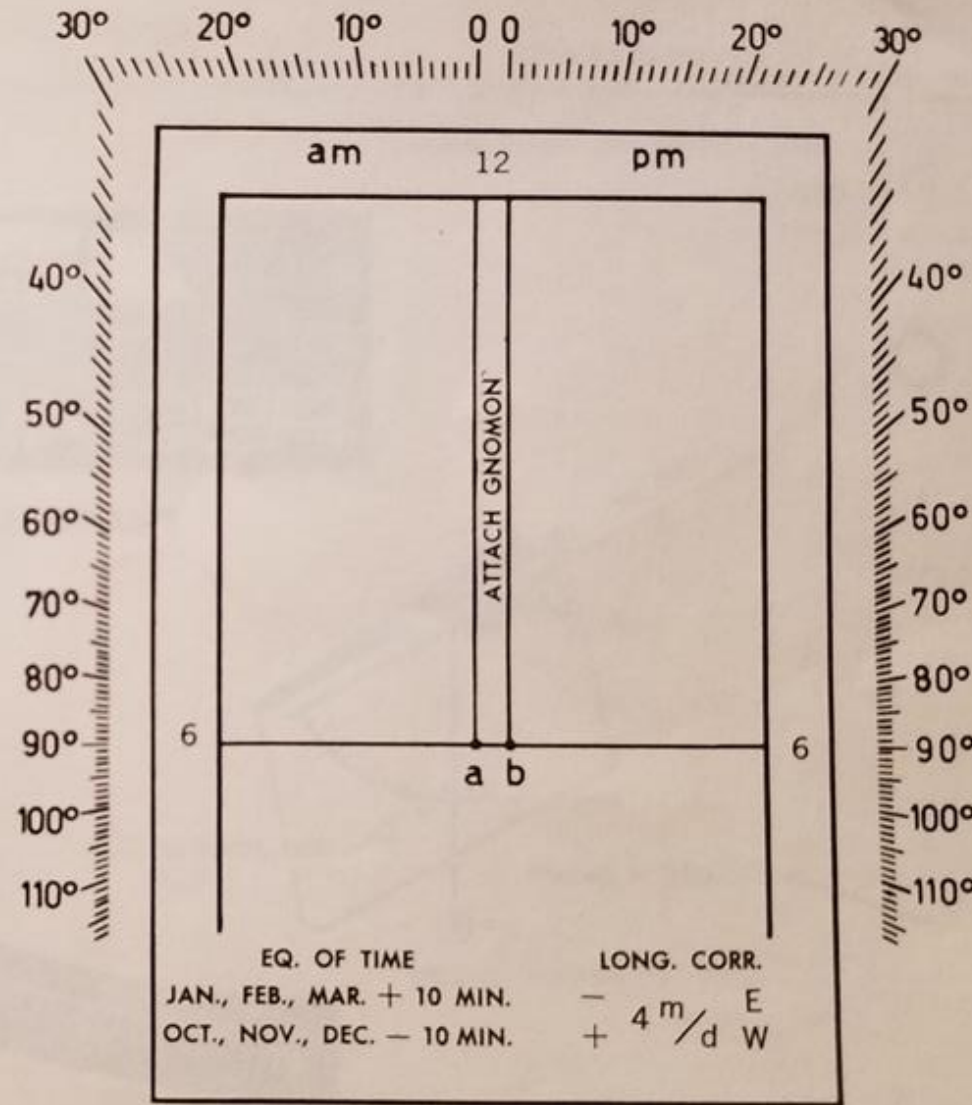
Equation of Time: The values shown are in minutes. Select the proper column, depending if you are converting from Apparent Time to Mean Time or vice versa. The sign shows whether the amount is to be added or subtracted to the current time.



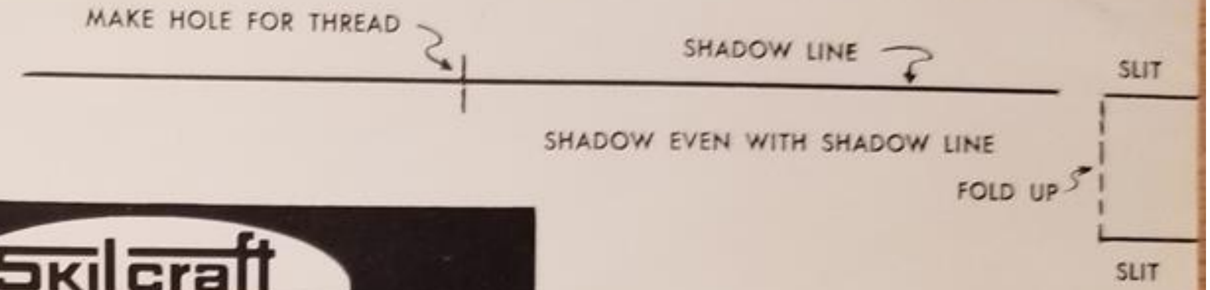
gnomon pattern



SUNDIAL MUST BE LEVEL



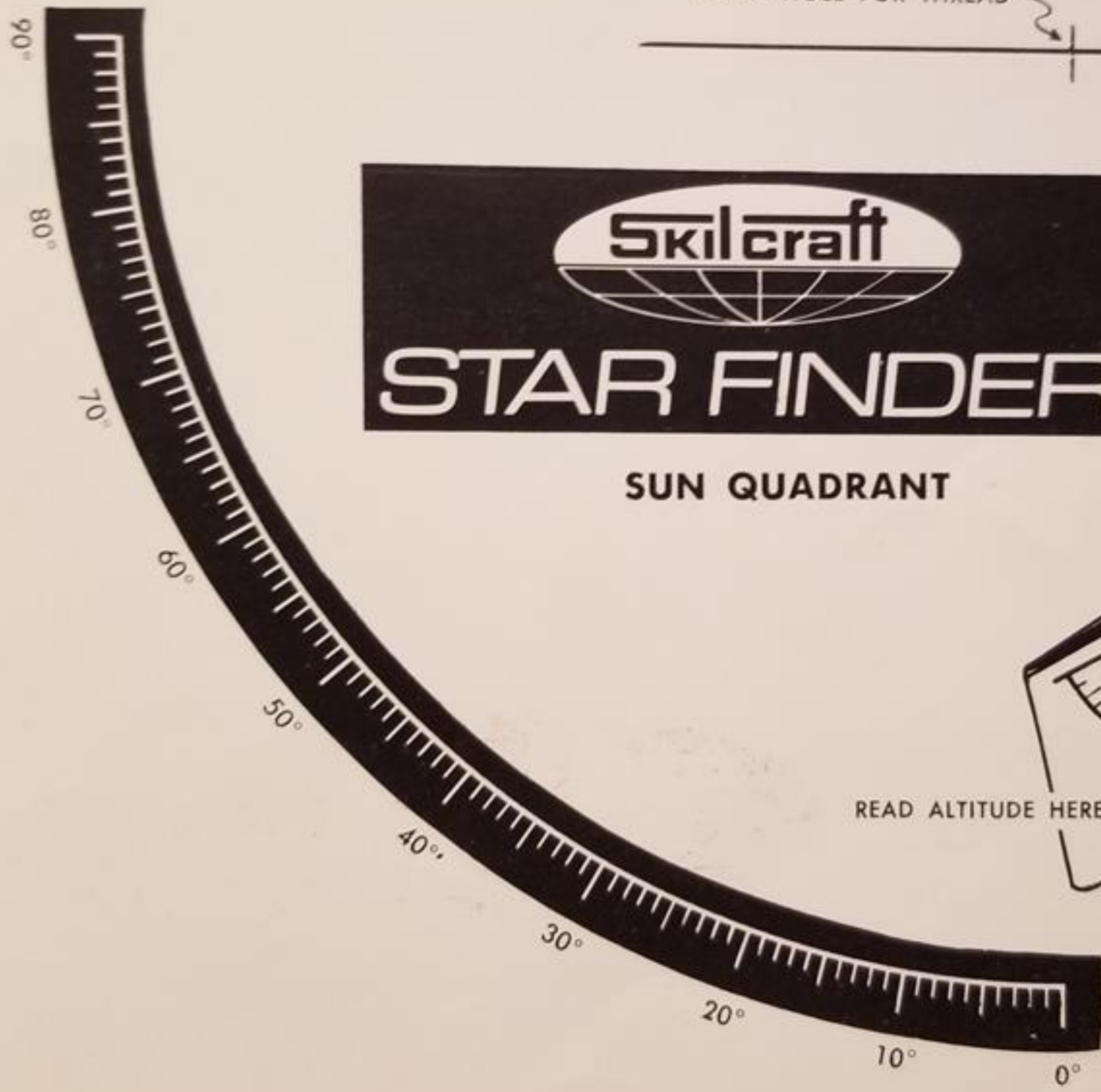
dial pattern

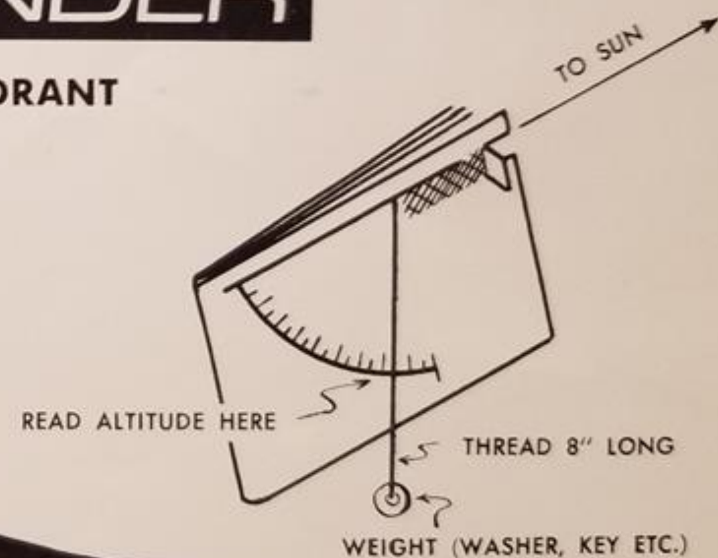


Skilcraft

STAR FINDER

SUN QUADRANT





Skilcraft

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