UNIGLOBE ARMILLARY SPHERE

INSTRUCTION MANUAL

Daniel Lee Wenger

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INTRODUCTION

From the earliest planetaria of Archimedes through the complex armillary spheres of the 17th Century to the present combination celestial and terrestial globes, man has produced devices to understand and teach relationships between heavenly bodies. In November 1973 the comet Kahoutec was being widely discussed. Its position coordinates were published, but this information did not suffice to determine where in the sky to look for the comet. Being a theoretical physicist, I was able to design a device that would give the desired information. I realized that such a device would be of value in education and have a great popular appeal. A prototype of the Uniglobe was complete in June of 1974. This device represents the 20th Century version of the armillary sphere, an analog computer of practical value.

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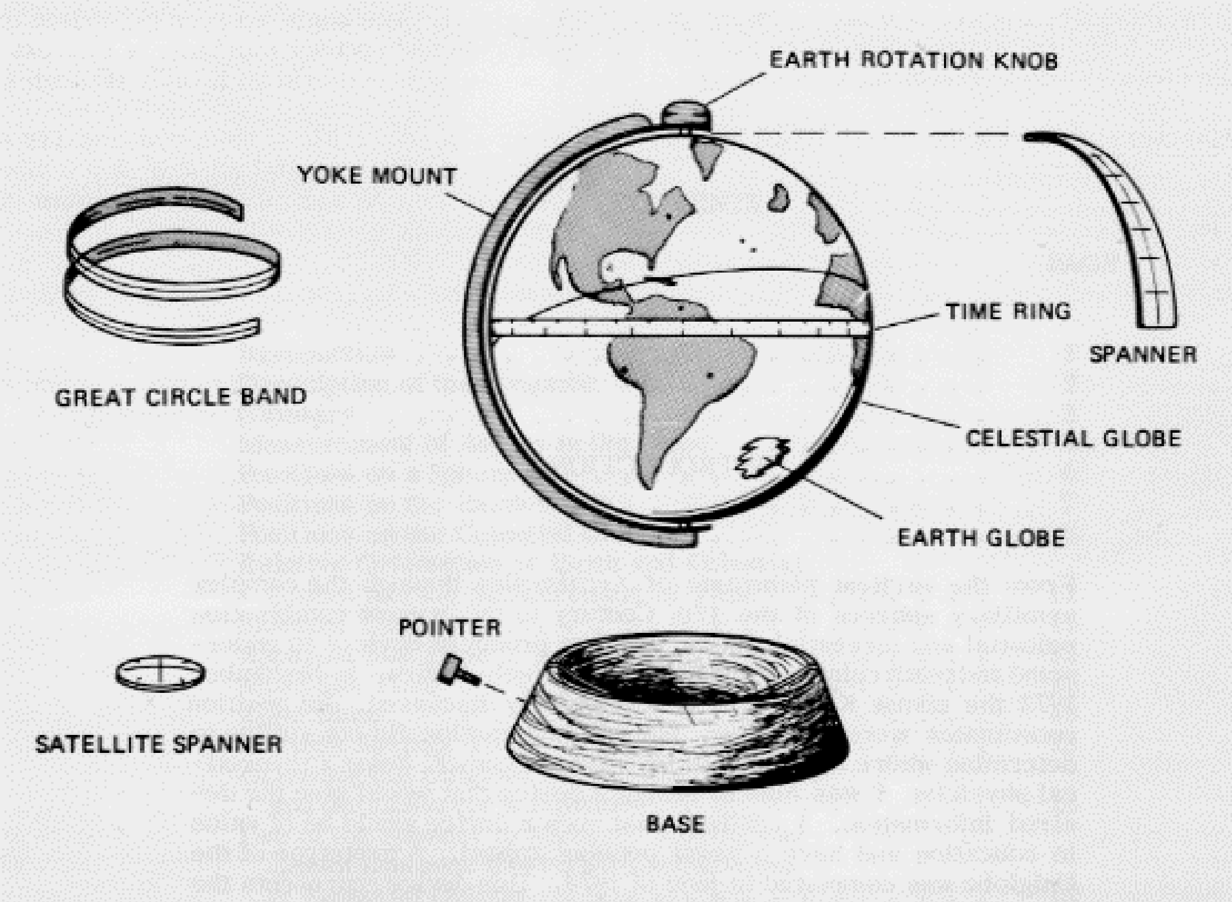

Figure 1. Elements of the Uniglobe

DESCRIPTION OF THE UNIGLOBE

The Uniglobe is a WORLD GLOBE immediately surrounded by a transparent CELESTIAL GLOBE upon which are marked the stars and other pertinent celestial data. The two globes are supported by a YOKE MOUNT which rests in a slotted BASE for orienting the AXIS toward any direction. A braking system allows the celestial globe to be turned independently and the two globes to be turned simultaneously. A TIME RING at the equator of the celestial globe allows setting of the earth and celestial globes according to the time of day. The time ring is movable allowing use of any of the systems of time measurement in use.

A measuring device, the SPANNER, allows determination of zenith angle and bearing of a celestial object from any pont on the earth. A POINTER indicates the direction of a celestial object at a given time and conversely, when the pointer is directed towards the sun, the Uniglobe becomes a sun dial. The Uniglobe is supplied with a SATELLITE SPANNER for indicating the region of visibility of a satellite and a GREAT CIRCLE BAND for indicating satellite orbits. A graphical and tabular ephemeris is supplied to allow plotting of the positions of the sun, moon and planets.

Altitude. Angular distance above the horizon: the arc of a vertical circle between the horizon and a point on the celestial sphere, measured upward from the horizon.

Angle. The inclination to each other of two intersecting lines, measured by the arc of a circle intercepted by the two lines forming the angle, the center of the circle being the point of intersection.

Angular Distance. The angle between two directions as seen from a given point.

Apogee. That orbital point farthest from the earth when the earth is the center of attraction (as in the case of the moon).

Apparent sun. The actual sun as it appears in the sky.

Apparent time. Time based upon the rotation of the earth relative to the apparent (true) sun.

Azimuth. The horizontal angle between a reference direction and another direction of interest. It is measured from 0° at the reference direction clockwise or counter clockwise through 360.

Bearing. The horizontal angle between a reference direction and another direction of interest. It is usually measured from 0° at true north clockwise through 360°.

Celestial body. Any aggregation of matter in space constituting a unit, such as the sun, a planet, etc.

Celestial Sphere. A sphere concentric with the earth, on which all celestial bodies except the earth are imagined to be projected.

Coordinate. One of a set of magnitudes defining a point in space.

Declination. The angular distance north or south of the celestial equator: the arc of an hour circle between the celestial equator and a point on the celestial sphere, measured northward or southward from the celestial equator through 90°, and labeled N or S to indicate the direction of measurement.

Ecliptic. The apparent annual path of the sun among the stars.

Equator. The primary great circle of the earth, or a similar body, perpendicular to the polar axis.

Equinox. One of the two points of intersection of the ecliptic and the celestial equator, or the instant the sun occupies one of these points, when its declination is 0°.

Great circle. The intersection of a sphere and a plane through its center.

Hour circle. A great circle perpendicular to the celestial equator.

Latitude. The angular distance north or south of the equator and a point on the surface of the earth, measured northward or southward from the equator through 90°, and labeled N or S to indicate the direction of measurement.

Longitude. The angle between the prime or reference meridian and another meridian of interest, measured from the prime meridian E or W through 180°.

Mean sun. A fictitious point conceived to move eastward along the celestial equator at a uniform rate equal to the average rate of the apparent sun along the ecliptic.

Meridian. A great circle perpendicular to the equator.

Parallax. The difference in the apparent direction or position of an object when viewed from different points.

Perigee. That orbital point nearest the earth when the earth is the center of attraction (as in the case of the moon).

Polar distance. The angular distance from a celestial pole, usually the elevated pole.

Precession. The change in the direction of the axis of rotation of a spinning body, as a gyroscope, when acted upon by a torque.

Prime meridian. The meridian of longitude 0° used as the origin for the measurement of longitude.

Sidereal day. The duration of one rotation of the earth on its axis, with respect to the vernal equinox.

Sideral hour angle. The angular distance west of the vernal equinox; the arc of the celestial equator, or the angle at the celestial pole, between the hour circle of the vernal equinox and the hour circle of a point on the celestial sphere, measured westward from the hour circle of the vernal equinox through 360°

Sidereal time. Time based upon the rotation of the earth relative to the vernal equinox.

Solar day. The duration of one rotation of the earth on its axis, with respect to the sun.

Vernal equinox. That point of intersection of the ecliptic and the celestial equator, occupied by the sun as it changes from south to north declination on or about March 21, or the instant this occurs.

Zenith distance. The angular distance from the zenith.

MEASUREMENT OF ANGLES IN THE PLANE

The measurement of angles is the basic concept required for definition of the celestial environment. Consider the circle shown in Figure 2. Our basic frame of reference in measuring angles is the circle. The circle is considered to be composed of 360 separate parts, each of which is called a DEGREE. Thus, the angle between A and B shown in Figure 2 is 15 divisions, or 15°. The symbol for a degree is °.

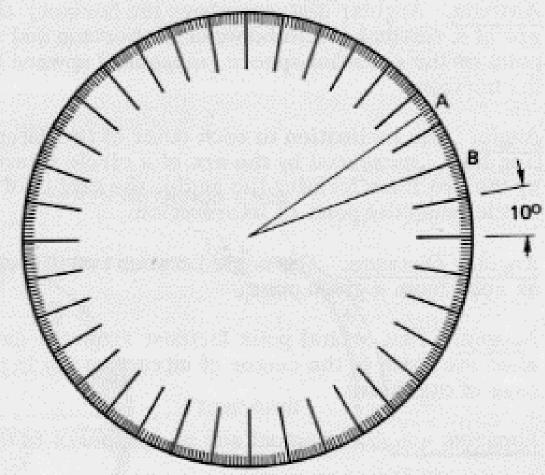

Figure 2. Divisions of the Circle

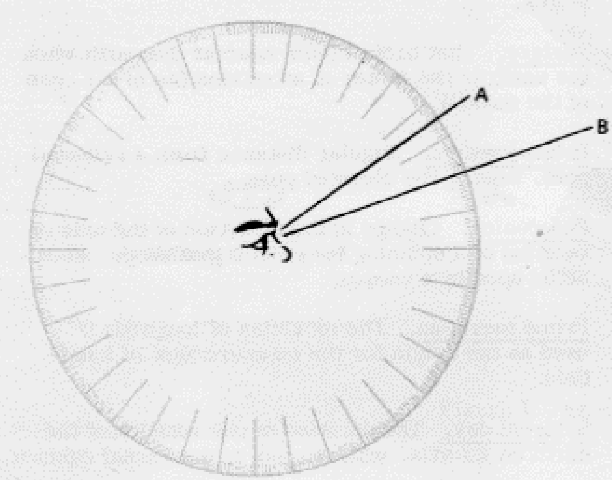

Figure 3. Basic Angle Measurements

In Figure 3, the observer's eye can determine the angle between two objects, assuming that he has some type of measuring device. It is important to remember that the distances from the observer to the objects may be changed without affecting the angle: thus object A can be anywhere on the line through it and the observer and object B can be anywhere on the line through it and the observer.

Using the spanner, which is essentially a device for measuring angles, as shown in Figure 4, the angle between objects A and B can be determined with some accuracy. The use of the spanner involves the use of an angular scale which is different from the scale on the circle in that the linear distances between marks differ. The spanner is an arc of a circle with a radius of approximately 6 1/4 inches. The circle is of a radius of approximately 2 inches. However, the angles measured with either device are the same. To use the spanner, the observer's eye must be at a point 6 1/4 inches from the spanner. (At the center of the circle defined by the spanner). Angles in any plane can be measured by rotating the spanner.

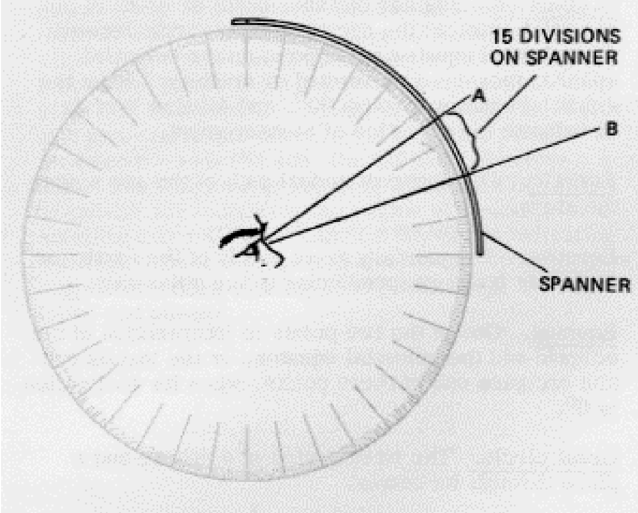

Figure 4. Angle Measurements with the Spanner

EXERCISES

1. Measure the angle between the top and the bottom of a tree or telephone pole (measurement of an angle in the verticle plane). See Figure 5.

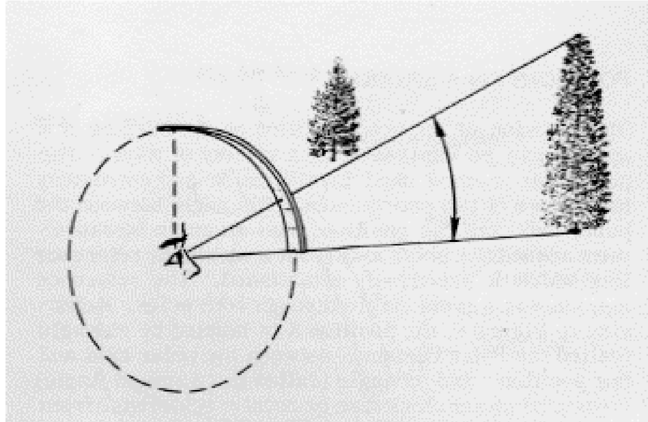
Figure 5. Angle Measurement in the Vertical Plane

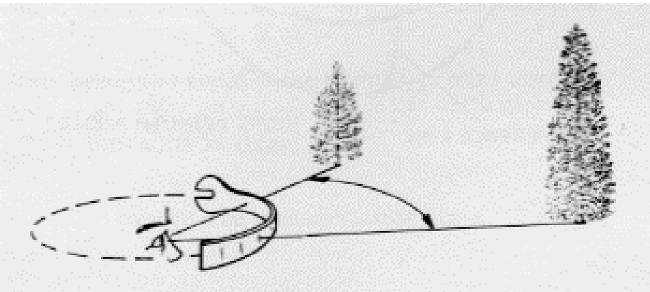
Figure 6. Angle Measurement in the Horizontal Plane

2. Measure the angle between the bottoms of two trees or telephone poles (measurement of an angle in the horizontal plane.). See Figure 6.

3. Measure the angle between the top of one tree or telephone pole and the bottom of another (measurement of an angle in a slanted plane.) See Figure 7.

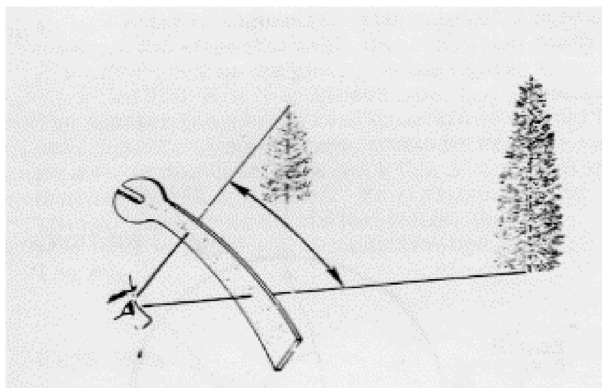
Figure 7. Angle Measurements in Slanted Planes

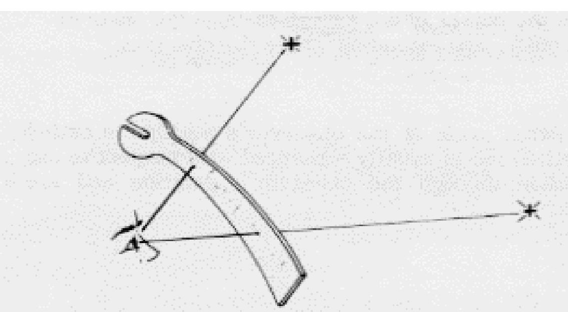
Figure 8. Angle Measurements in the Sky

4. Measure the angle between two prominent stars in the sky (angles can be measured in any plane). See Figure 8.

POSITIONS ON A SPHERE

The location of an exact position on the surface of a sphere can be expressed in a variety of ways. The particular method used in navigation and astronomy makes use of two coordinates. The angle between the polar axis and the position, and an angle measurement around the polar axis from a meridian reference line which is arbitrarily established. The reference meridian is a great circle through both poles. Referring to Figure 9, the position A is labeled by an angle (called the Polar Distance) between the polar axis and the position, and an angle (called the Azimuth Angle) measured either clockwise or counter-clockwise from the reference line. The polar angle can be measured directly from the cursor scale on the spanner. The azimuthal angle between the reference meridian and the spanner cursor can be measured directly from the rosetta on the spanner, or between the intersection at the equator of the reference line and the spanner cursor.

For positions in the southern hemisphere, polar distance is measured from the south pole and labeled with an S.

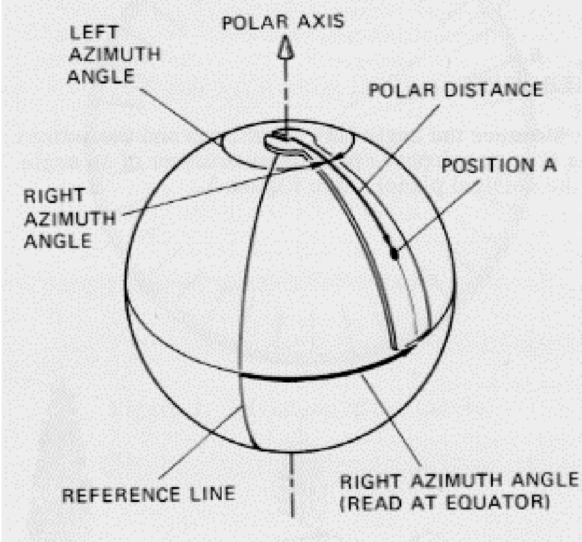

Figure 9. Angle Measurements on a Sphere

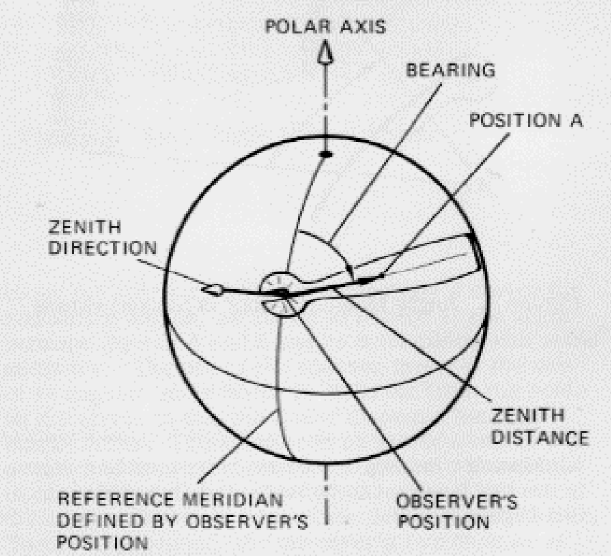

Figure 10. Angle Measurements from Local Position

The same types of measurements are used to determine positions with respect to the position of the observer. Referring to Figure 10, the spanner is positioned with the spanner rosetta centered over the observer's position, and the spanner cursor line lying on position A. The angle measured between the observer's position and position A is called the ZENITH DISTANCE. The observer's location and the center of the sphere define the ZENITH DIRECTION. The zenith direction is an imaginary line from the center of the sphere through the observation point, and extending above the observer.

Azimuthal angle at the observer's position is called BEARING and is usually measured with respect to the meridian through the observer's position and the poles.

POSITIONS ON THE EARTH GLOBE

The system described in Figure 9 is used with the EARTH GLOBE, as shown in Figure 11. The polar distance is the angle between the polar axis and the zenith direction at Position A. The complementary value, called LATITUDE is the angle distance from the equator to Position A. Latitude equals 90° - polar distance and is North or South of the equator.

The measurement between meridians on the earth globe is called LONGITUDE, and is referenced to the Prime or Greenwich Meridian, which passes through both poles and Greenwich, near London, England. Longitude is specified as either West or East longitude, depending on whether the direction lies West or East of Greenwich. Conventionally, the maximum longitude vale is 180 W or E. The maximum latitude vlaue is 90° N or S.

This system of coordinates permits precise description of any point on the surface of the earth globe, using the reference points noted.

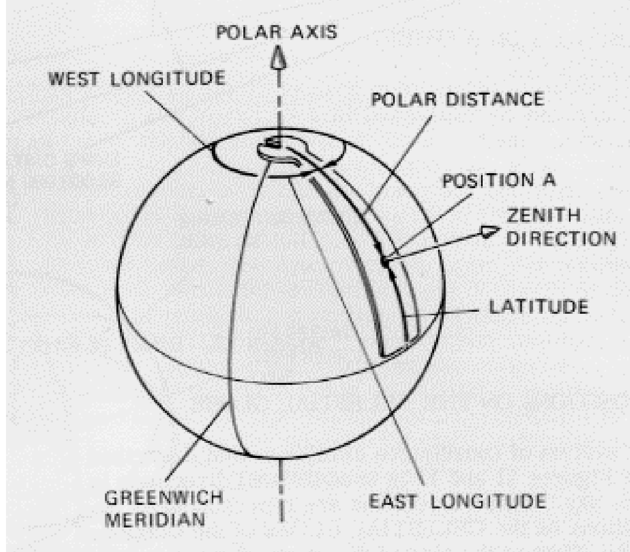

Figure 11. Position Coordinates on Earth Globe

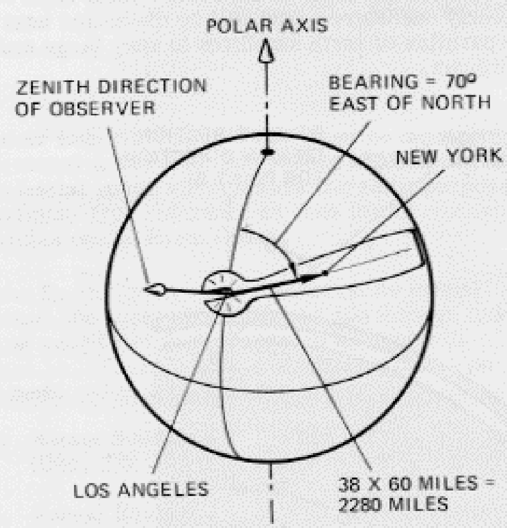

Figure 12. Earth Globe Positions Using Local Reference System

The system described in Figure 10 of referring positions to the observer is also used on the earth globe. Refer to Figure 12. The spanner is used to measure the azimuthal angle (bearing) from North to another point on the globe. In the figure, New York lies 70° E of N as viewed from Los Angles. The spanner can also be used to determine actual linear distance along the great circle between the two points. In this case, New York lies 38 divisions or degrees from Los Angeles. Each division on the spanner represents 60 nautical miles, therefore New York is 38x60=2280 nautical miles from Los Angeles.

EXCERCISES

1. Measure the distance from New Orleans to Port Guinea (on the W. Coast of Africa). What is the bearing?

Answer: 4800 mi., 6° N of East.

2. Measure the distance from Port Guinea to Moscow. What is the bearing?

Answer: 45000 mi., 30° E of North.

3. Measure the bearing from London to Mecca. (20° N, 39° E).

Answer: 120° E of N.

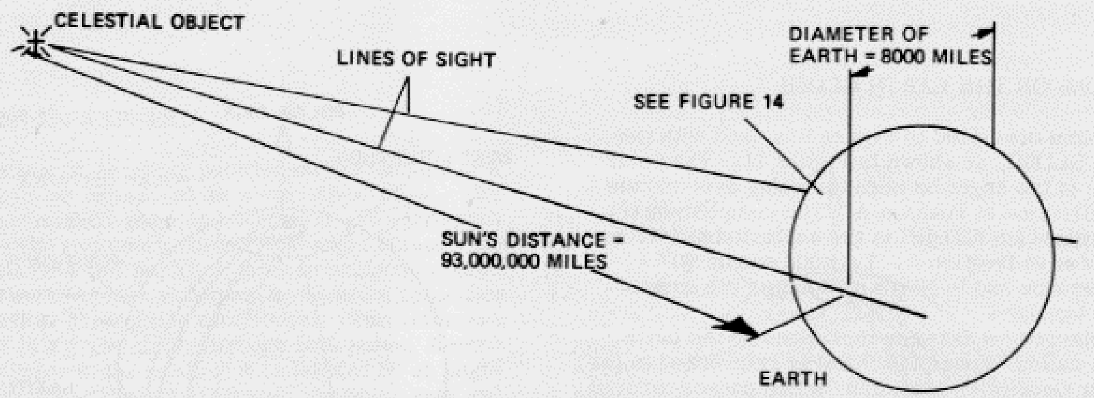

Figure 13. Effect of Earth Size on Polar Distance

POSITIONS ON THE CELESTIAL GLOBE

A system of coordinates similar to that described in Figures 11 and 12 is used to label directions in the sky. These directions are represented as positions on the CELESTIAL GLOBE of the Uniglobe. The effect of the size of the earth on measurement of angle is shown in Figure 13. The extremely large distances from the earth to a celestial object, compared to the radius of the earth, results in making the lines of sight effectively parallel. This means that the measurement of polar distance for a distant star will be essentially the same when measured from any point on the earth's surface. DECLINATION, the complement of polar distance, will also be the same.

Figure 14 demonstrates how the positions of celestial objects are located on the celestial globe by extending an imaginary line from the center of the earth to the celestial object. The location of the celestial object is indicated at the point where the imaginary line intersects the surface of the celestial globe. The polar directions at all observation points are considered parallel, and the lines of sight to the celestial object are considered parallel, therefore the polar distance to the celestial object will be the same at any point on the earth's surface and at the earth's center. In the case of objects near to the earth, lines of sight directions are not parallel and the difference is significant, (called PARALLAX). In the case of distant stars and planets, the parallax is less than 1/60th of a degree. The parallax of the moon varies from zero to nearly one degree, and will be discussed later. The parallax of earth satellites is very large and significant.

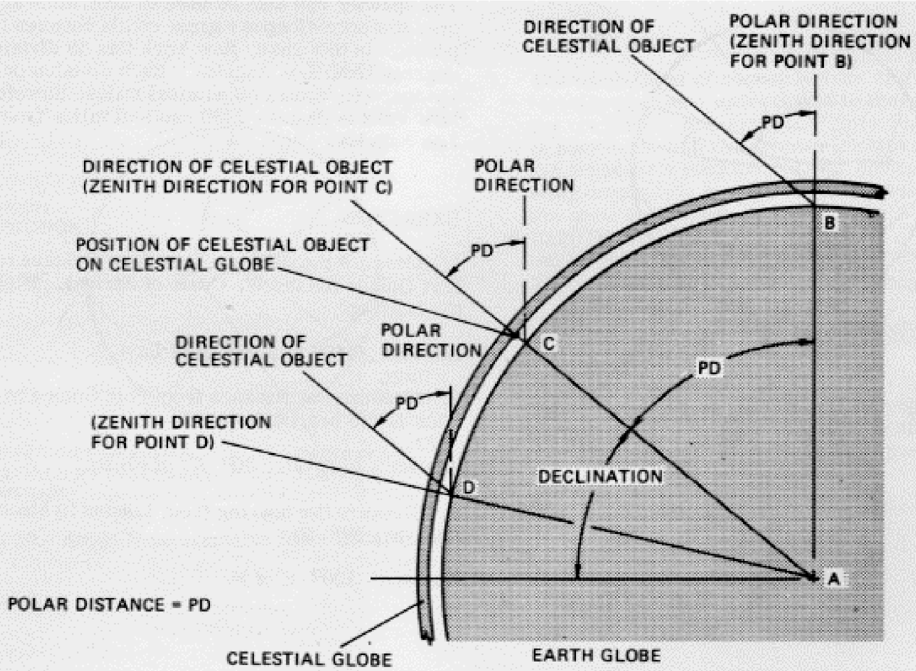

Figure 14. Location of Celestial Objects

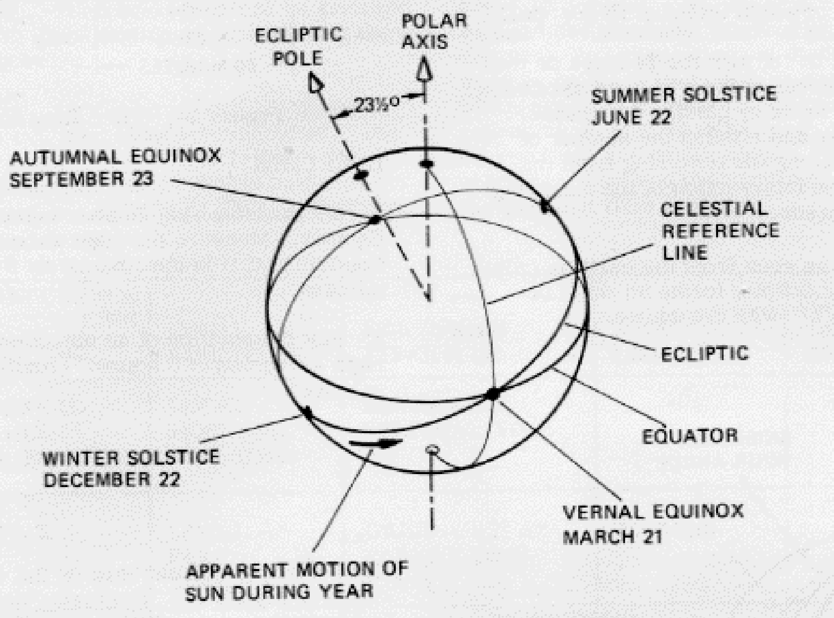

Figure 15. Apparent Path of the Sun as Seen from Earth

Another important point which must be thoroughly understood is the establishment of a reference line in celestial space which serves the same purpose of azimuth-type reference as does the Greenwich Meridian of the Earth Globe.

As the Earth moves about the sun on its annual journey, the apparent path of the sun through the sky as seen from Earth, appears as shown in Figure 15. There are four significant points on this path:

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1. Winter Solstice (Dec. 22) .... When the sun is at its most southerly point
2. Vernal Equinox (Mar. 21) .... When the sun crosses the equator on its way north
3. Summer Solstice (June 22) .... When the sun is at its most northerly point
4. Autumnal Equinox (Sept. 22) .... When the sun crosses the equator on its way south

The celestial reference line is defined as the meridian that passes through the vernal equinox. All references comparable to E longitude are called RIGHT ASCENSION. References comparable to W longitude are called SIDEREAL HOUR ANGLE and are usually specified in hours and minutes from the Vernal Equinox.

In specifying right ascension and sidereal hour angle, angle measurements are based on the division of the circle into 24 equal parts, each of which contains 15 degrees. Each 15° segment represents an hour and is further divided into 60 minutes. Thus, there are 60/15 = 4 minutes per degree. The Uniglobe time ring has two scales. See Figure 16. The upper shows degrees. The lower scale is divided into 24 segments, each of which includes 15 degrees.

When the time ring is set with the 24 mark on the vernal equinox, a direct reading of right ascension of any star may be made by placing the spanner cursor over the star and reading the number of hours and minutes along the time ring from the vernal equinox to the intersection of the time ring with the spanner cursor.

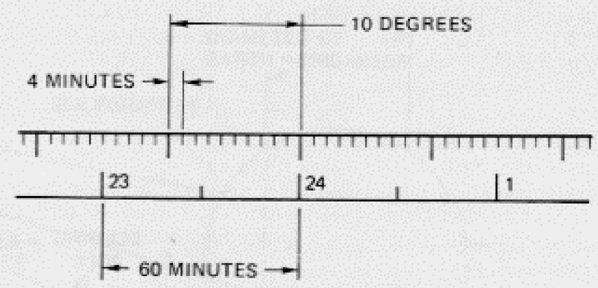


Figure 16. Time Ring Scales

The path of the sun as seen from the earth is called the ECLIPTIC. The ecliptic forms an angle of approximately 23 1/2° with the equator.

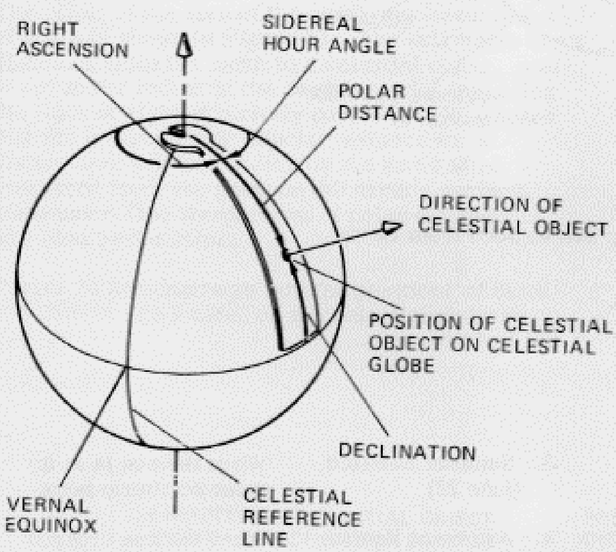


Figure 17. Celestial Reference System

EXERCISES

1. Set the time ring 24 hour mark on the Vernal Equinox. Measure the right ascension of RIGEL. Confirm that it is approximately5 hours and 12 minutes.

2. Plot the position of an object on the ecliptic at right ascension of 6 hours. (Position of summer solstice).

The reference system used on the celestial globe is shown in Figure 17. The term DECLINATION is used to denote the angle which was called LATITUDE on the earth globe. All other terms are analogous. For example: the declination of Vega is 37° N, and the right ascension is approximately 280° or 18 hours 35 minutes.

EXERCISE

1. Plot a star on the celestial globe whose position is 6 h 43 m right ascension and 16 1/2° S. This star is the brightest star in the sky, Sirius.

As in the case of the Earth Globe, angle measurements may be made with the spanner between points on the celestial globe. Since these points are not at the same distance from the earth, the spanner cannot represent linear distance between objects in the sky. Figure 18 shows the angle measurement between Vega and Deneb as 25°.

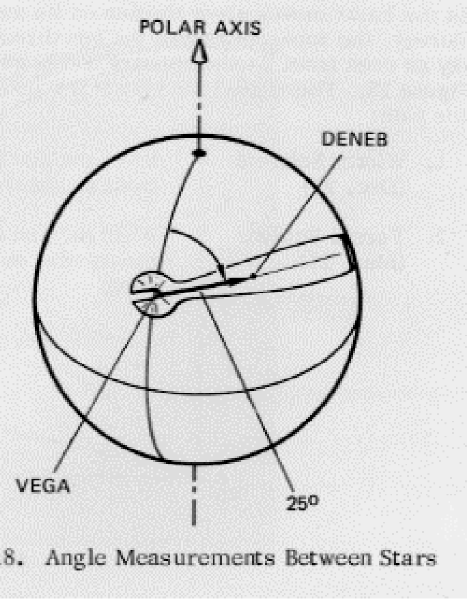


Figure 18. Angle Measurements Between Stars

RELATIVE ORIENTATION OF EARTH AND CELESTIAL GLOBES AND THE MEASUREMENT OF TIME

The earth's rotation upon its polar axis can be represented by holding the celestial globe firmly on its axis and rotating the earth globe, by means of the earth rotating knob, counter-clockwise as viewed from the North pole. The same effect can be achieved by holding the earth globe stationary and rotating the celestial globe clockwise.

As the earth rotates, a reference longitude on the earth will cross a celestial reference meridian. The period between two such crossing is called a DAY. When the celestial meridian is the prime celestial meridian, the period is a SIDERIAL DAY. When the celestial meridian is that of the sun, the period is an APPARENT SUN DAY. A measurement of the angle between the terrestial reference longitude and the celestial reference meridian represents a measurement of the time of day.

The time ring on the Uniglobe is divided into 360 degrees on its upper scale, with longer graduations every 10 degrees. The lower scale is divided into 24 one-hour segments (each of which contains 15 degrees), and graduations at the half hour and 15 minutes points. There are several time systems which are used to measure the passage of time, depending on what specific earth and celestial reference lines are used. Figure 19 shows the various reference lines and the terminology used to define the different time systems.

EARTH REFERENCE LINE / CELESTIAL REFERENCE LINE	LOCAL LONGITUDE	GREENWICH LONGITUDE	ZONE LONGITUDE	ZONE LONGITUDE 15° TO THE EAST
0 HOURS ON VERNAL EQUINOX = 12 HOURS ON AUTUMNAL EQUINOX	LOCAL SIDEREAL TIME (LST)	GREENWICH SIDEREAL TIME (GST)		
12 NOON ON SUN'S POSITION	LOCAL AP-PARENT SUN TIME (LAT)	GREENWICH AP-PARENT TIME (GAT)		
12 NOON ON MEAN SUN'S POSITION	LOCAL MEAN SUN TIME (LMT)	GREENWICH MEAN SUN TIME (GMT)	STANDARD MEAN SUN TIME	DAYLIGHT SAVINGS MEAN SUN TIME

Figure 19. Standard Time Systems

SIDEREAL TIME

Siderial time corresponds to placing the time ring with 1200 at the autumnal equinox. This position corresponds to setting the zero mark at the vernal equinox. Local sidereal time (LST) can then be read for any longitude at its intersection with the time ring. Greenwich Sidereal Time (GST) is read at the intersection of the Greenwich meridian with the time ring.

Figure 20 shows the setting of the time ring for sidereal time, and the reading of GST as 0400 hours.

QUESTIONS

1. When GST is 0400 what is LST at Cairo, Egypt?

Answer: (0604).

2. When GST is 0400 what is LST at San Francisco?

Answer: (1945), or 7:45 P.M.

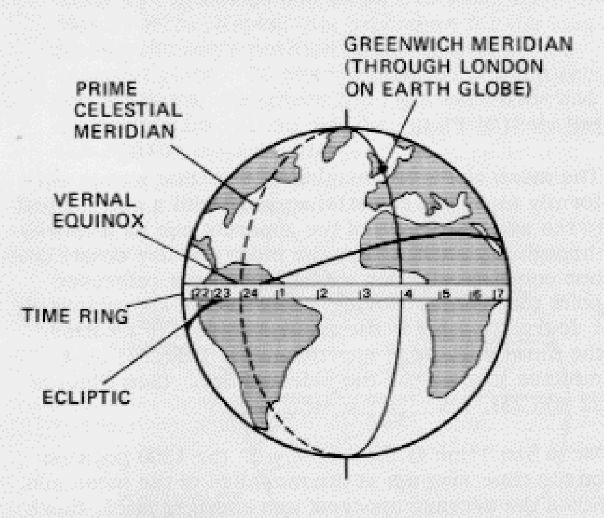


Figure 20. Time Ring Setting for Sidereal Time

APPARENT SUN TIME

Apparent sun time is measured by placing the 1200 position of the time ring at the meridian of the sun's current position in the sky. This position is given in the graphical ephemeris for the current date, or can be estimated by interpolating for the current date between the dates shown along the ecliptic on the Uniglobe. Local Apparent Sun Time (LAT) can be directly read forr any longitude at its intersection with the time ring. Figure 21 shows the 1200 position set at the position of the sun for November 22, and the earth globe oriented for 1100 hours in Rio de Janeiro. The local Apparent Sun Time in Dakar, Senegal is 1245 when it is 1100 hours in Rio. The Local Apparent Sun Time is 1200 or noon for any obervation oint when the sun is due north or south of that point.

Greenwich Apparent Time (GAT) is the Local Apparent Sun Time at the Greenwich meridian. When apparent sun time at Rio de Janeiro is 1100, GAT is 1350.

The apparent sun day differs from the sideral day by 3 1/2 to 4 1/2 minutes. This is due to the fact that the sun's position in the sky moves about 1° during the time that it takes the earth to rotate once. The precise difference depends upon two factors. One is the earth's varying speed in its elliptical orbit around the sun during the year. The other is due to the inclination of the ecliptic to the equator. Near the solstices, the sun moves to the east, during a day, a greater amount than when it is near the equinox.

To have a unit of time which is approximately equal to the apparent sun day and of the same length throughout the year, the concept of the mean sun is introduced.

MEAN SUN TIME

The mean sun is an imaginary point that moves uniformly along the celestial equator with a speed equal to the average speed of the apparent sun as it moves through the year. Since the mean sun day constitutes one complete rotation with respect to a reference point that is also moving at the rate of approximately 1 degree per day in the same direction of rotation, the mean sun day is approximately 1 degree or 4 minutes longer than the sidereal day. (See Figures 22 and 23).

Mean Sun Time is measured with the 1200 position on the time ring set at the meridian of the mean sun. Since the average apparent sun speed is used, there is no variation in the length of the mean sun day.

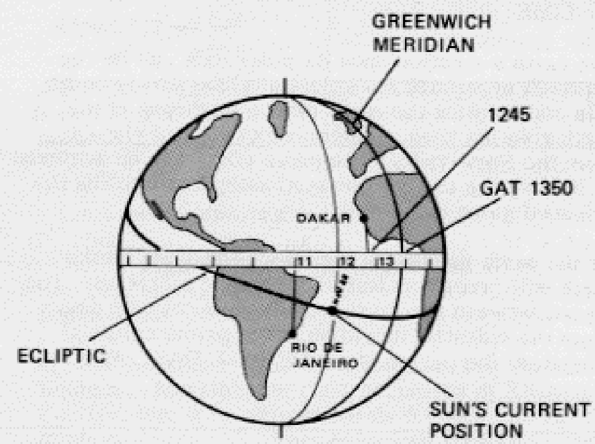


Figure 21. Time Ring Set for Apparent Sun Time on Nov. 22.

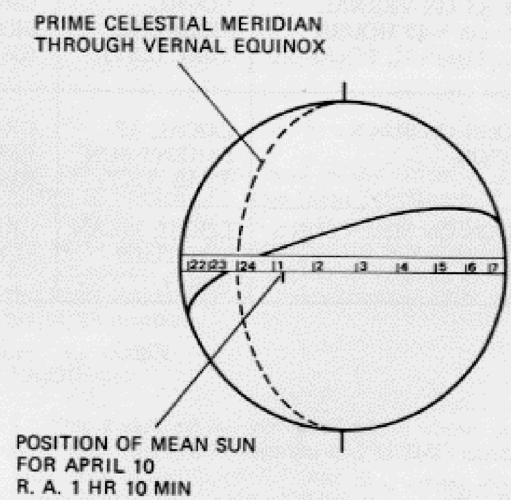


Figure 22. Time Ring Used to Plot Mean Sun

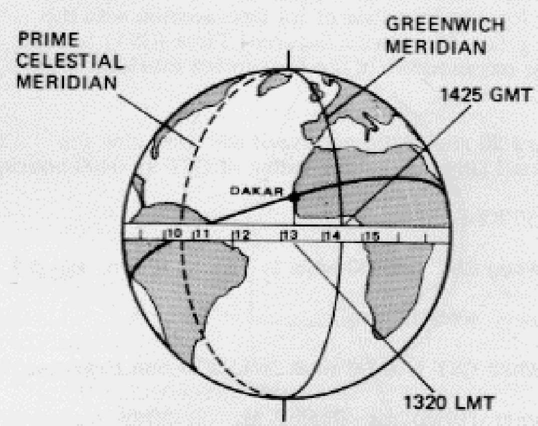


Figure 23. Time Ring Set for Mean Sun Time on April 10.

The position of the mean sun can be determined by finding the position of the apparent sun from the ephemeris and adding the correction from the tabular ephemeris.

For example: In the ephemeris on April 10, 1975, the sun's position is 1 h 11 m R.A. On this date the position of the mean sun is -1 m from the position of the sun. With the 2400 mark of the time ring set on the vernal equinox, mark on the celestial globe near the time ring the position of the mean sun 1 h 11 m + (-1 m) = 1 h 10 m R. A. (See Figure 22). This is the position of the mean sun on April 10. Now set the 1200 mark of the time ring on the position of the mean sun. Local Mean Sun Time can then be read directly from the time ring at any particular meridian on the earth globe for any orientation of the two globes. In Figure 23, the two globes are oriented at 1320 local mean sun time (LMT) in Dakar, therefore at that instant it is 0800 (LMT) in Mexico City. GMT is the Local Mean Sun Time on the Greenwich Meridian or 1425 in Figure 23.

EXERCISE 1. Set, for April 10th, the relative orientation of the two globes for 1545 LMT in Los Angeles. What is GMT? 2340 hrs.

THE EQUATION OF TIME

The position of the mean sun and the apparent sun differ during the year by up to approximately 16 minutes. This difference is called the EQUATION OF TIME. For any particular time of the year,

$$RA_{MS} - RA_{AS} = GAT - GMT$$ where:

RA_{MS} = Right Ascension of Mean Sun

RA_{AS} = Right Ascension of Apparent Sun

GAT = Greenwich Apparent Time

GMT = Greenwich Mean Time

This difference is given in the Ephemeris for any given date..

ZONE TIME

It is apparent from the previous discussion that times as measured at two particular locations separated by a few degrees of longitude are different.

As a matter of convenience, people have agreed to use certain standard longitude lines to measure time for everyday purposes. Thus, there are 24 standard longitude lines at 15° intervals about the earth. In general, people use the standard longitude line nearest to their location to measure their time. These lines are not always precise and may vary somewhat to follow geographic lines or political divisions. Wee find that generally the territory within + or - 7 1/2° of a standard line will be a time zone, but as in the case of the Arizona-California border which occurs close to standard longitude line of 120° W, the time zone boundary follows the state line.

DAYLIGHT SAVING TIME

It has been the practice, since the introduction of zone times, to alter the terrestrial reference line during the year to take maximum advantage of the longer hours of sunlight in the summertime. The conversion of standard time to daylight time is accomplished by using the next most easterly standard reference line. This results in a change of one hour between standard and daylight saving times. For example: when it is 0400 PST in Los Angeles, (120° W line coinciding with 0400 on the time ring) it is 0500 Pacific Daylight Savings time. (105 W line coinciding with the 0500 mark on the time ring).

ORIENTING THE UNIGLOBE FOR THE CURRENT TIME AND THE OBSERVER'S POSITION

Before orienting the Uniglobe for the current time, consult the ephemeris for the current date to determine the position of the mean sun and plot its position near the time ring on the celestial globe. Refer to Figures 24 and 25 for examples for May 1, 1975 Repeat this proceedure for the sun, placing the sun's position on the ecliptic on the celestial globe. To plot the position of the planets and the moon, determine the right ascension and declination for the current date and plot their positions on the celestial globe.

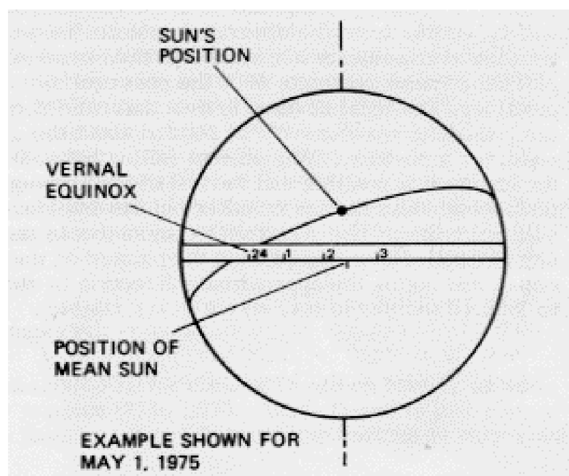
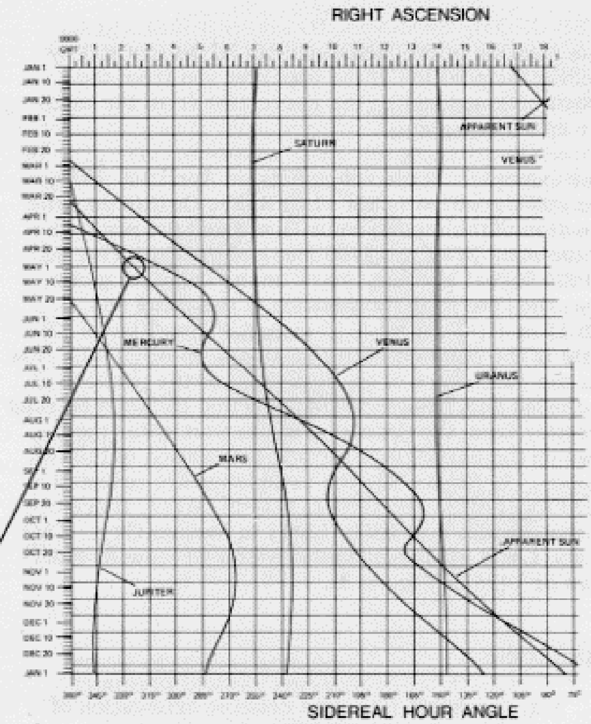


Figure 24. Time Ring Used for Plotting Right Ascension

SUN					EQUATION OF TIME CORRECTION	
	R.A.		DEC.			
DATE	hr	min	deg	m	DATE	min
Jan 0	18	39	-23	8	Jan 0	-3
10	19	23	-22	4	10	-7
20	20	6	-20	18	20	-11
30	20	48	-17	53	30	-13
Feb 9	21	28	-14	56	Feb 9	-14
19	22	7	-11	34	19	-14
Mar 1	22	45	- 7	54	Mar 1	-12
11	23	22	- 4	3	11	-10
21	23	59	- 0	6	21	-7
31	0	35	+ 3	50	31	-4
Apr 10	1	11	+ 7	38	Apr 10	-1
20	1	49	+11	14	20	+1
30	2	27	+14	31	30	+3
May 10	3	5	+17	24	May 10	+4
20	3	45	+19	48	20	+4
30	4	25	+21	39	30	+3
Jun 9	5	6	+22	52	June 9	+1
19	5	47	+23	25	19	-1
29	6	29	+23	16	29	-3



READ R.A. AT APPROX 2 HR 30M

VERIFY FROM TABLE, INTERPOLATE AS NECESSARY.

RA Apr 30 = 2H 27M RA May 10 = 3H 5M

DIFF = 38 MIN, X 1/10 = 2H 31M

Figure 25. How to Read the Graphical Ephemeris

Next, orient the Uniglobe with the polar axis pointing to the polar direction (North pole to the North, South pole to the South) and the observer's position in the zenith position as shown in Figure 26. Set the time ring with the 1200 on the mean sun, and orient the celestial globe to correspond with present zone time at the observer's position using the oberver's standard longitude. It is now possible to determine which celestial objects shown on the celestial globe will be visible from the obeserver's point. To determine which objects are visible to the observer, place the spanner rosetta over the observer's position. The local horizon is then determined by the end of the spanner as it is rotated about the observer's position. Any object falling between the observer's position and the end of the spanner (assuming no mountains or other objects interfere) will be visible. The direction to any object in the sky can be indicated by placing the pointer on the object and noting the approximate direction in which to look. (If the sun is out, no stars are visible..)

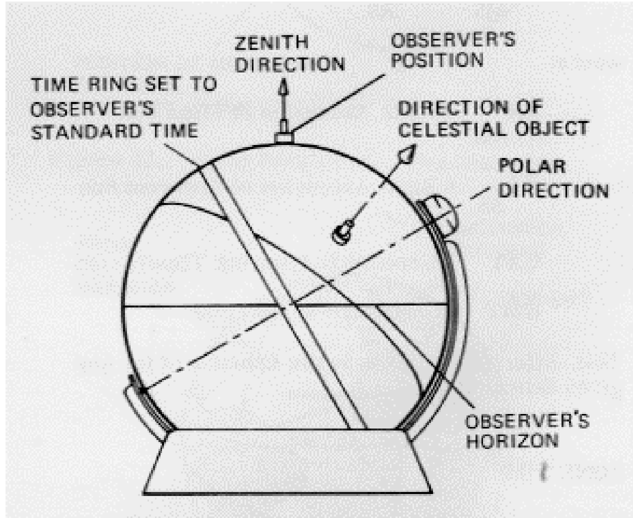


Figure 26. Orientation of Uniglobe to Determine Visible Objects

USE OF THE SPANNER TO MEASURE BEARING AND ZENITH DISTANCE (DIRECTION COORDINATES) OF CELESTIAL OBJECTS

The Uniglobe and its spanner may be used to determine direction coordinates, a more precise process than shown in Figure 26. With the two globes oriented for the current date and time as described previously, two definitve position coordinates may be measured with the spanner as shown in Figure 27.

To measure zenith distance to a celestial object place the spanner rosetta over the observation position, and the cursor line over the celestial object. The zenith distance from the position on the earth globe to the celestial object's position is measured directly on the spanner. For example, the zenith distance from Los Angeles to Procyon on May 1st at 1400 hours (Pacific Standard Time) is 47 1/2°.

To measure bearing to a celestial object, at a given time, read the angle from the roesetta between the cursor line and north. For example, with the conditions shown, the bearing from north to Procyon at Los Angeles is 112 1/2° E of N or 22 1/2° S of E.

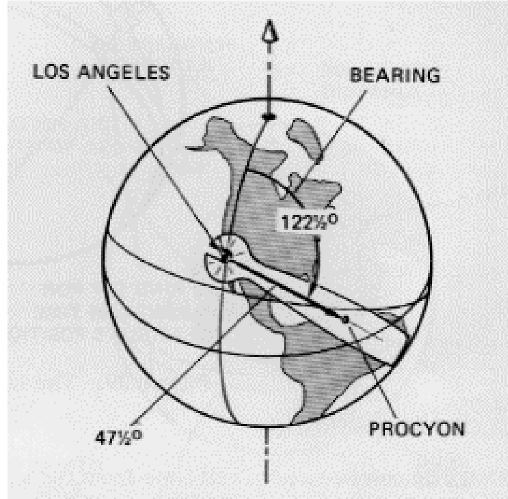


Figure 27. Use of Spanner for Bearing and Zenith Distance

TRANSIT TIME

It is possible to determine the time at which a celestial object is either due north or south of a given obeservation point. (This is called the TRANSIT TIME). This is accomplished by setting up the two glboes for the specific date and measuring the time that a specific celestial object passes through the meridian of the observation point. For example, the transit time of Rigel at Mexico City on May 1 is 1500 CST (note that Rigel will not be visible at transit because it is still daylight). Mexico City uses the time of the 90° standard longitude.

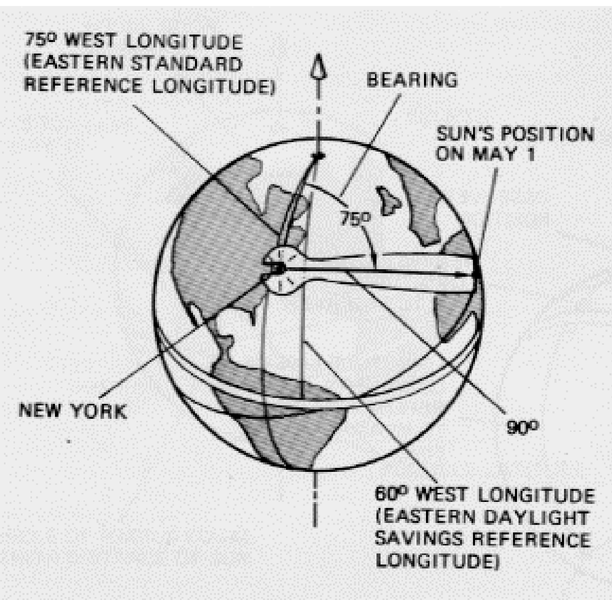


Figure 28. Determining Rising Time with Spanner

RISING AND SETTING TIMES

The rising and setting times of a celestial object can be determined for a specific observation point. The rising time of an object is that time when the object rises above the horizon in the East for a specific observation point (Zenith distance 90°). The setting time is that time when the object disappears over the horizon in the West (Zenith Distance 90°). See Figure 28. To determine the rising time of the sun as seen from New York on May, place the spanner rosetta on New York, and rotate the celestial sphere until the 90° mark on the spanner cursor intersects the position of the sun on May 1 east of New York. The local Mean Standard Time can then be read directly on the time ring at 75° W meridian as 0505 EST. Since New York would be on Daylight Savings time, the time at longitude 60° W would be sued, or 0605 EDST. The bearing of the sun when it rises is approximately 15° N of E. The sun at that time is directly overhead in Sudan, and almost due south of Helsinki, Finland. The sun's setting time in New York on May 1 (90° Zenith Distance) is 1930 EDST or 7:30 P.M.

EXERCISE

Determine rising time of Deneb on May 1, as seen in Jamaica (2250 EST). When Deneb is just rising in Jamaica, it is 18° above the horizon in New York..

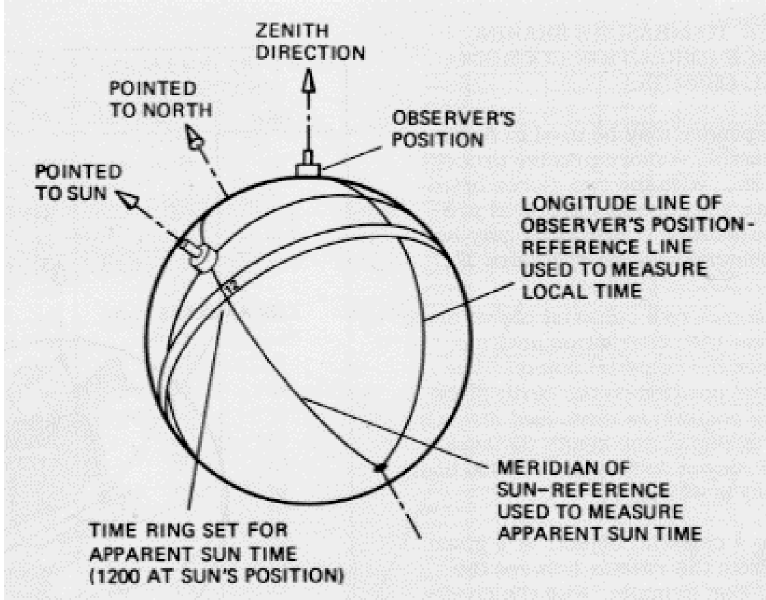


Figure 29. The Uniglobe as a Sun Dial

UNIGLOBE AS A SUNDIAL

The Uniglobe can be used to tell time from the sun's position by orienting the earth globe so that the observer's position is at zenith, and the polar axis is pointing in the polar direction. See Figure 29. Place the pointer on the sun's position (determined from the ephemeris) and rotate the celestial globe until the pointer's shadow disappears (the pointer is then directly pointed at the sun). This establishes the orientation of the two globes for the particular day and hour. The time ring is now rotated to the particular time system desired:

Sidereal Time	24 on Vernal Equinox
Apparent Sun Time	12 on Sun's position (from ephemeris)
Mean Sun Time	12 on Mean Sun Position (from ephemeris)

The time at a particular observation point is now read at the intersection of the time ring and the earth reference line. (See Figure 30). (Nearest standard longitude for standard mean time, local meridian for local time, etc.).

Note that this method may be used to tell time using any celestial object on the celestial sphere. For instance, if Arcturus is in transit in Hawaii on May 1, then it is 2350 Hawaii Standard Time (150° W).

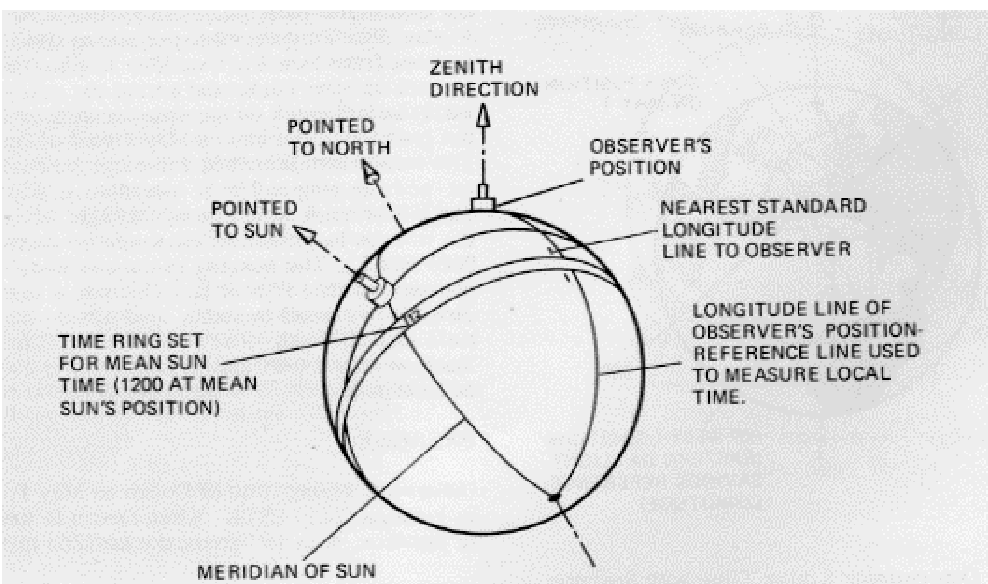


Figure 30. Determining Time from Time Ring

CELESTIAL NAVIGATION

Celestial navigation in general depends upon being able to establish the orientation of the earth globe with respect to the celestial glboe (i.e., the time of day). If sidereal time is known it is possible to determine one's position on the earth by using the Uniglobe and spanner. It should be noted that stellar navigation is essentially based on sidereal time. If GMT is known, it must be converted to sidereal time before calculations can be made.

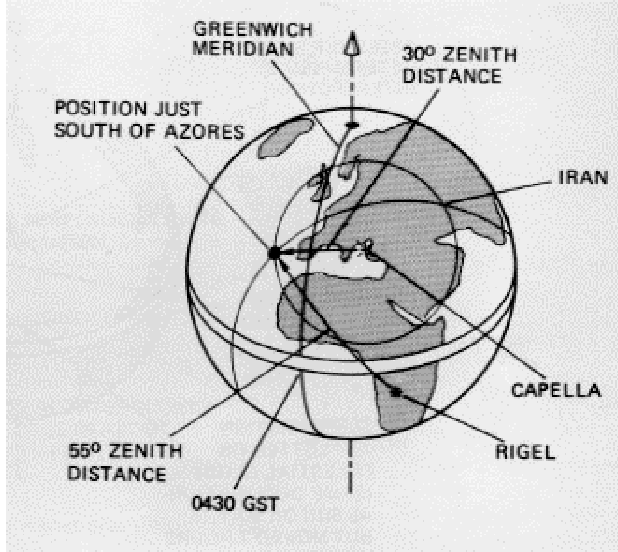


Figure 31. Determining Position with Two Star Sights

Refer to Figure 31. Assume that an observer aboard a ship knows that the time is 0430 GST, and looks into the heavens and observes the stars Rigel and Capella. Using the spanner, he measures the altitude (i.e., the angle from the horizon) of Capella as 60°. (Thus, zenith distance is 30°) and the altitude of Rigel as 35° (zenith distance 55°. By orienting the spanner rosetta over Capella, a circle of 30° radius can be drawn around the star. This circle represents all of the possible positions at which the observer may be. The circle represents all points having a zenith distance from Capella of 30°. If a circle of radius 55° is also plotted around Rigel on the Uniglobe, the circle will intersect the Capella circle at two points. Thus, there are only two places on the globe where these two conditions exist.

By orienting the two globes for 0430 GST, (24 on vernal equinox and 0430 on Greenwich) we find that at this time, one of the two points appears in the Atlantic, and the other in Iran. The ambiguity is resolved since the obeserver is known to be in the Atlantic. A third measurement and plot, perhaps of Deneb (altitude 36°) would also resolve the ambiguity, or the observer could note that Capella is in the eastern sky, not the western sky. This is an example of celestial navigation which does not require the use of an almanac or an ephemeris, just a catalogue of star positions. This type of calculation can be performed using any of the fixed celestial objects (the navigational stars).

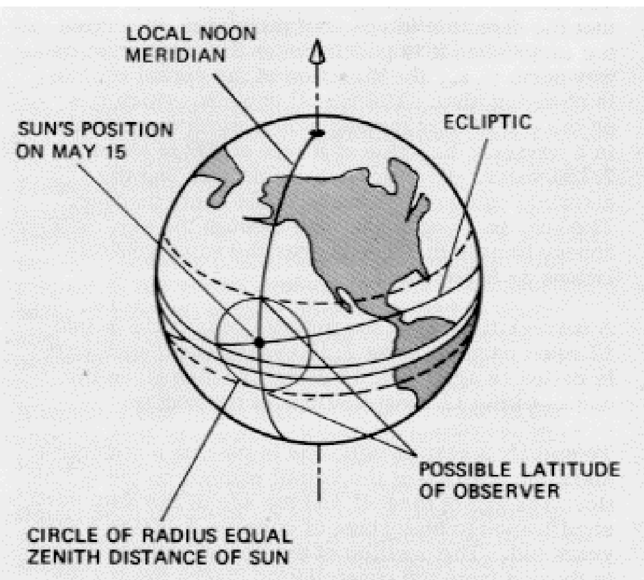


Figure 32. Determining Latitude from Zenith Distance

The navigation process can also be performed using moving celestial objects such as the sun, moon or planets, but the positions of these objects for the particular date and time of day must be known. This requires an almanac or ephemeris, together with a knowledge of GST or GMT.

The normal SUN SHOT requires going to the ephemeris or almanac to determine the sun's position for the current time. The sun's declination is approximately known using only the date and without knowing the time of day. The determination of one's latitude alone may be performed by measuring the sun's altitude at local noon or transit.

For example, assuming it is the 15th of May, it is easy to approximate the sun's position from an interpolation of the dates on the ecliptic of the Uniglobe, which estabishes the declination of the sun for that date. The latitude is determined by first computing the zenith distance from the measured altitude at local noon. (90° - altitude= zenith distance). By drawing a circle about the sun of radius equal to the zenith distance, two possible latitudes are determined, one directly north of the sun and one south. This ambiguity is easily resolved by observation. (See Figure 32). celestial objects (the navigational stars).

During the daylight hours there is generally only one celestial object visibile, the sun. To determine longitude during the day, two observations of the sun are made with a known period of time between observations to develop two zenith circles about two different positions of the sun. Here it is easiest to position the celestial globe for the earliest time reading and to plot the second position of the sun on the celestial globe as an object at the same declination as the sun's first position but moved westward by an amount determined by the time interval between sightings. The observer's position is then determined in the same way as it is done with two stars. (See Figure 33). PRECESSION OF

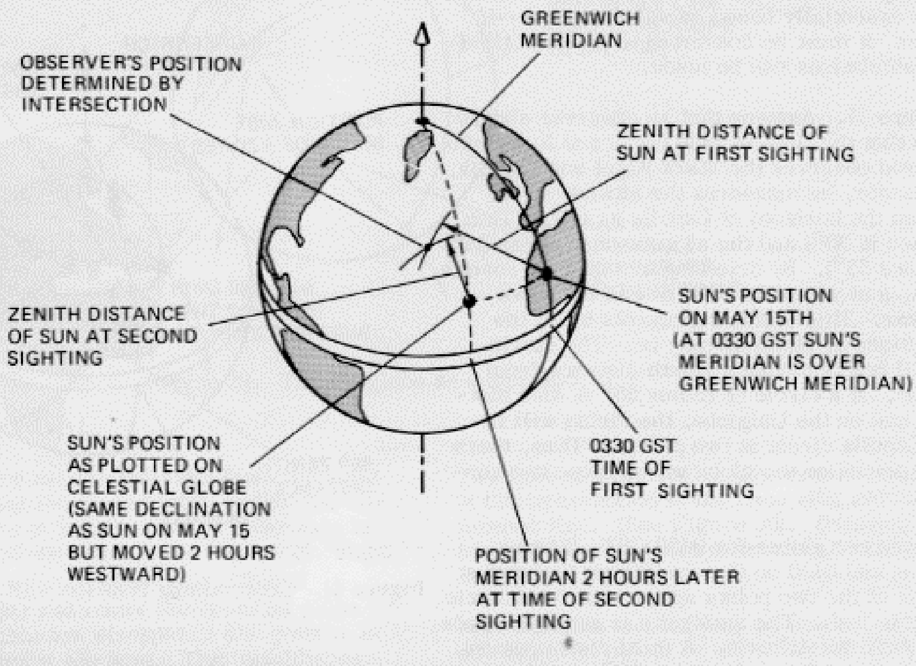


Figure 33. Determining Position from Two Sun Shots

THE EQUINOXES

The positions of stars with respect to the earth change slowly in a regular way. This change is associated with the change in the direction of the axis of rotation of the earth. The North pole now points approximately towards the star Polaris. About 4,000 years from now, the polar axis will be pointing near the direction of Vega, a star that now passes overhead in San Francisco.

This change in direction of the axis of the earth is similar to the motion of a spinning top as it precesses about the vertical. In the case of the earth, the vertical is a direction perpendicular to the orbit of the earth about the sun during the year. This direction is called the pole of the ecliptic, and the polar axis of the earth moves about this direction once in about 25,800 years. See Figure 34. Presently, the earth's axis maintains an angle of approximately 23 1/2° with respect to the pole of the ecliptic, however, during the 25,800 year precessional cycle, the angle of the polar axis to the pole of the ecliptic decreases approximately 3°. Thus, the path of the polar axis shown on the Uniglobe represents a spiral.

The change in the direction of the polar axis means that the direction in space of the sun as seen from the earth when it is passing over the equator on its way north (i.e., the direction of the vernal equinox) is changing also. The vernal equinox, which lines on the ecliptic, is moving slowly alobng the ecliptic in a westerly direction at a rate of 30° in about 2,150 years. Of course, the solstices and the autumnal equinox also move in the same manner. The sun, in its apparent path through the sky, will appear to pass through or near the same constellations as it now does.

A natural division of the precessional cycle is into 12 equal parts of about 2,150 years each: each part is called an age. The 12 parts are then given the names of the 12 constellations of the zodiac.

To specify a certain age, one is making a statement about the position of the vernal equinox on the ecliptic. The age of the Bull and the age of the Ram have significance to historians of cultures 2,000 to 6,000 years old. The position of the vernal equinox today is moving from the constellation Pisces toward the constellation Aquarius and this leads to the expression heard today that we are entering the age of Aquarius.

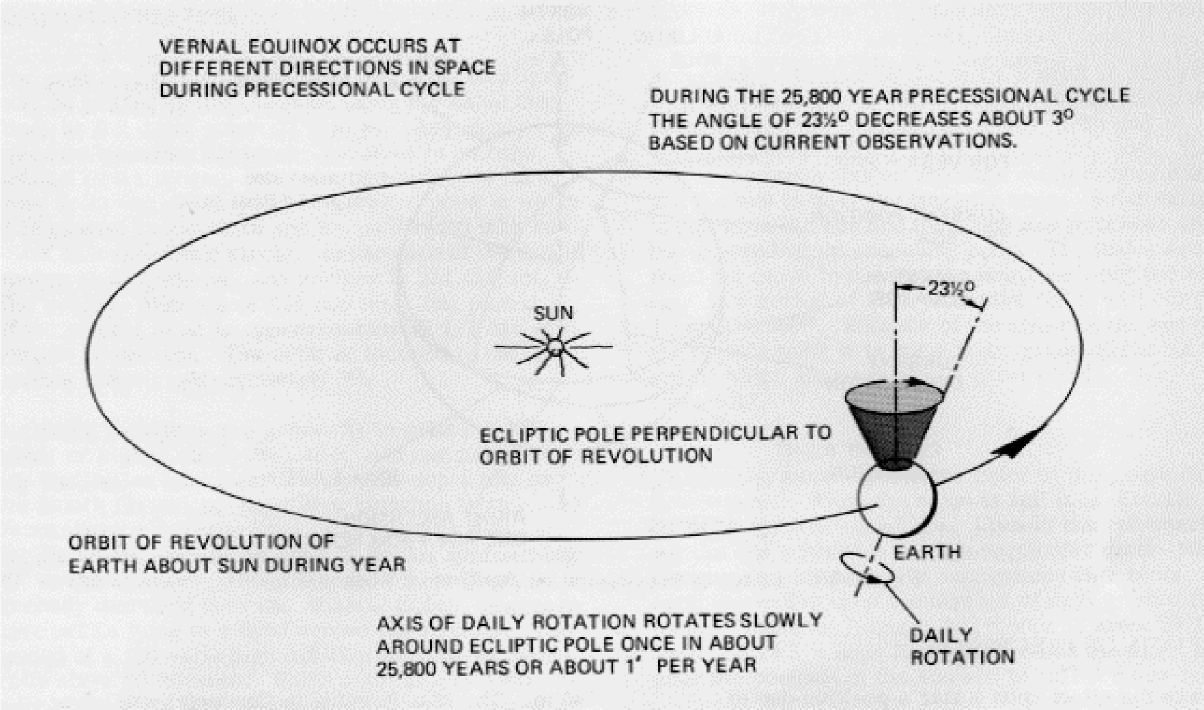


Figure 34. Movement of Earth About the Ecliptic Pole

Historically, there has been the convention of dividing the ecliptic into 12 regions (Zodiacal Regions) of 30° each and labeling each region with the name of the constellation that falls in that region. About 2,000 years ago, the vernal equinox was between the constellations Aries and Pisces and the vernal equinox was named the First Point of Aries; that is, the position of the sun was just entering Aries at the vernal equinox. At that time, there was the adoption of a division of the ecliptic into twelve 30 degree regions, a division that maintained its relationship to the vernal equinox.

Thus, with respect to this new division of the ecliptic, the vernal equinox defined the separation between the two 30° regions called Pisces(e) and Aries(e). Today, some ephemerides are published giving the positions of the sun, moon and planets as so many degrees into Taurus, for example. This is a precise way of specifying positions along the ecliptic with respect to the vernal equinox, but the historical basis of labeling of the regions can lead to confusion, since the statement does not say that the object is near the constellation Taurus.

It appears that in the attempt to be precise in the specification of positions along the ecliptic by the introduction of the fixed 30° divisions of the ecliptic with respect to the equinox, one has lost a continuity with the past. A system of time measurement existed that reflected a knowledge of the precession of the equinox and a labeling of the time by the specification of the position of the vernal equinox along the ecliptic (i.e., the age of the Bull, etc.).

The Uniglobe uses two notations to specify between the two different divisions of the ecliptic. See Figure 35.

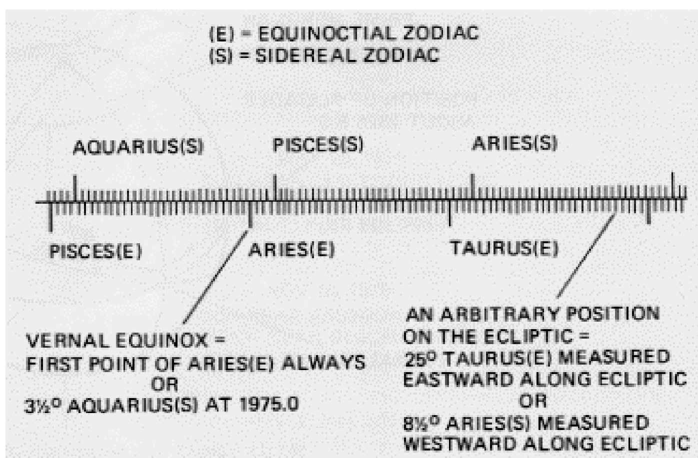


Figure 35. Ecliptic Scales

On the lower scale, along the ecliptic, are twelve divisions with a boundary at the vernal equinox. The divisions are labeled to the east by Aries(e), Taurus(e), etc., where the (e) stands for equinoctial. In this system the vernal equinox is always at the First Point of Aries. On the upper scale is a division of the ecliptic which is considered fixed with respect to the stars. On this scale, the vernal equinox moves to the west and is now at 3 1/2° Aquarius(s). The other regions of the sidereal zodiac are named by the constellations lying in them followed by (s) standing for sidereal. (Note that this is a definition of the fixed or sidereal(s) zodiac with respect to the vernal equinox of 1975.0).

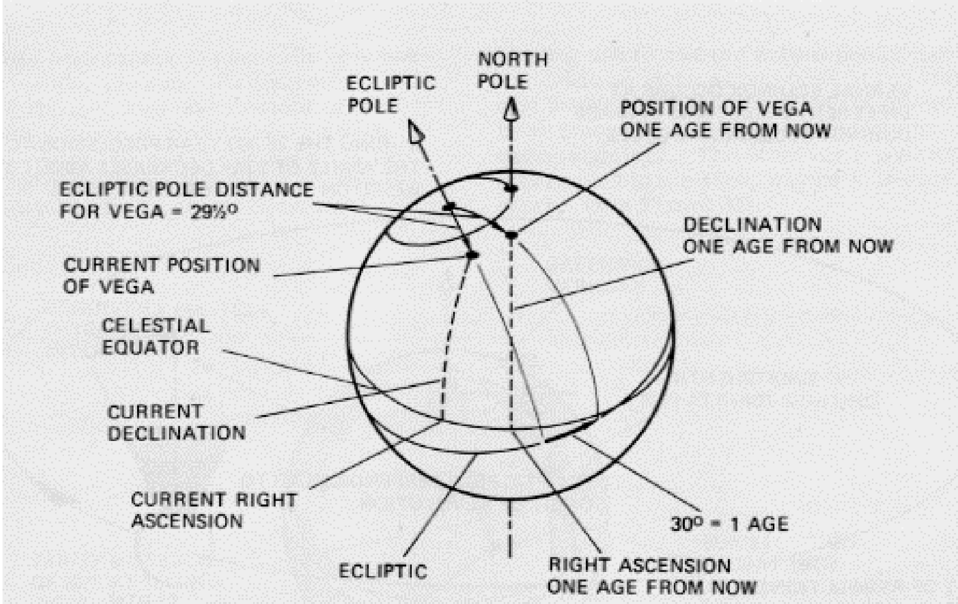


Figure 36. Effect of Precession on Position of Vega

EFFECTS OF PRECESSION

To see the effect upon a star's position due to precession, it is only necessary to move the star's position on the celestial globe about the pole of the eclioptic by a given angle. See Figure 36. If we are interested in the position of Vega one age from now or 2,150 years from now, in the year 4125 A.D. we move the current position of Vega counter-clockwise about the north ecliptic pole by 30°. Its current distance from the ecliptic pole is 29 1/2° and after it is move it will still be 29 1/2° from the ecliptic pole, but in a position about half-way beween the current postions of Vega and Deneb. Its declination will be 42° and its R.A. will be 19 h 40 m. Of course all other stars will also have moved. Polaris, the current pole star will be at a polar distance of 12°, and its R.A. will be 12 h 45 m. Here we have ignored the change in the declination of the earth's pole with respect to the ecliptic.

The star Regulus in Cancer(s) will have moved down to a position almost over the equator.

To go back in time we must move the stars in a clockwise direction about the north ecliptic pole. For example, tow ages ago (60° clockwise), or 4,300 years ago in the year 2,325 B.C., the Pleiades were about 4° north of the equator and just west of the vernal equinox. See Figure 37. In fact, the Pleiades were used by some people to indicate the beginning of the new year. When the Pleiades were on the meridian at midnight, the sun was at the autumnal equinox and the new year was started. About 2 1/6 ages ago, (65° clockwise) or about 2,600 B.C., the star Thuban or Alpha Draconis was the pole star. It is believed that the descending tunnel in the Great Pyramid Cheops was aligned to sight towards Thuban at its lower culmination.

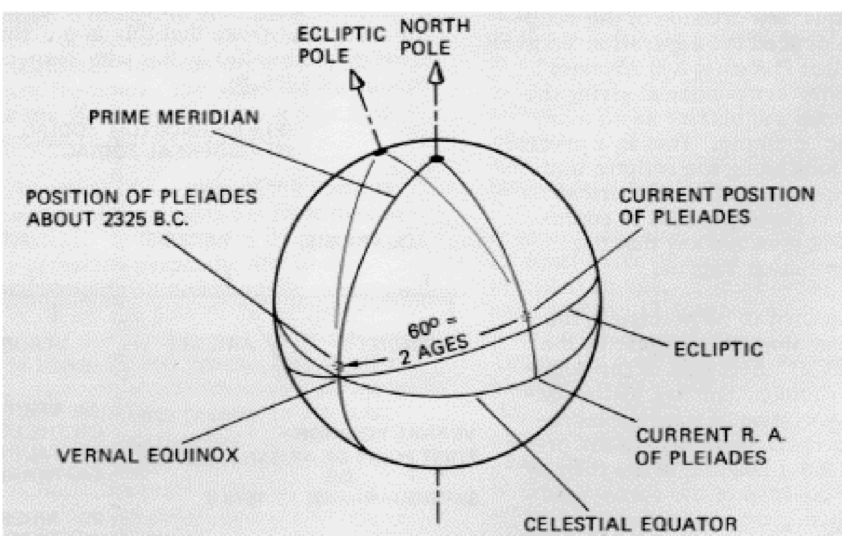


Figure 37. Effect of Precession on the Position of Pleiades

EARTH SATELLITES

The positions of the moon and other earth satellites may be plotted on the Uniglobe using the same methods as for other celestial objects. Any earth satellite including the moon, revolves in an orbit defined by its APOGEE, the point at which it is furthest from the earth, and PERIGEE, the point at which it is closest to the earth and its inclination with respect to a reference circle. In the case of the moon, apogee is 253,000 mi. and perigee is 21,000 mi. The average distance is 238,000 mi. The period of the moon's orbit is approximately 29 1/2 days with respect to the sun. The orbit is inclined to the earth's ecliptic approximately 5°.

Artificial satellites are generally in orbits of 100 miles or higher above the earth and can assume any inclination to the earth's equator depending on the launch direction. Satellites launched from Vandenberg Air Forece Base, south across the Pacific Ocean assume an orbit at angles approaching 90° to the equator. Those launched from Cape Kennedy eastward over the Atlantic Ocean, generally have orbits lying in a band around the equator. The period of a 100 mile high orbiting satellite is generally about 90 minutes. Earth satellites in 2,200 mile high orbits have a period of 24 hours (stationary orbit).

These satellites are used for radio, television and telphone relays between continents and are usually equatorial orbits.

Referring to Figure 38 the moon's orbit is described by a descending node which is the point at which the moon passes the ecliptic on its way south and and ascending node 180° from the descending node. Eclipses of the moon appear when the moon is near a node and the sun is near the opposite node. Solar eclipses occur when the sun and the moon are both near either the descending or ascending node. The nodes are not fixed but move in a westerly direction along the ecliptic. In a period of 18.9 years the nodes will complete 1 cycle of 360°. Because of the effect of the sun on the moon's orbit it is not a true great circle but a spiral which approximates a great circle. See Figure 39.

To plot the moon's position, refer to the graphical ephemeris. When the moon is full it is directly opposite the sun's position. Consult the ephemeris for the sun's position for any particular date. When the moon is not full, it is somewhere else in its orbit depending upon the number of days from a full moon. The time between full moons is about 29 1/2 days, so 14 3/4 days froma full moon the moon is near the position of the sun and is called a new moon.

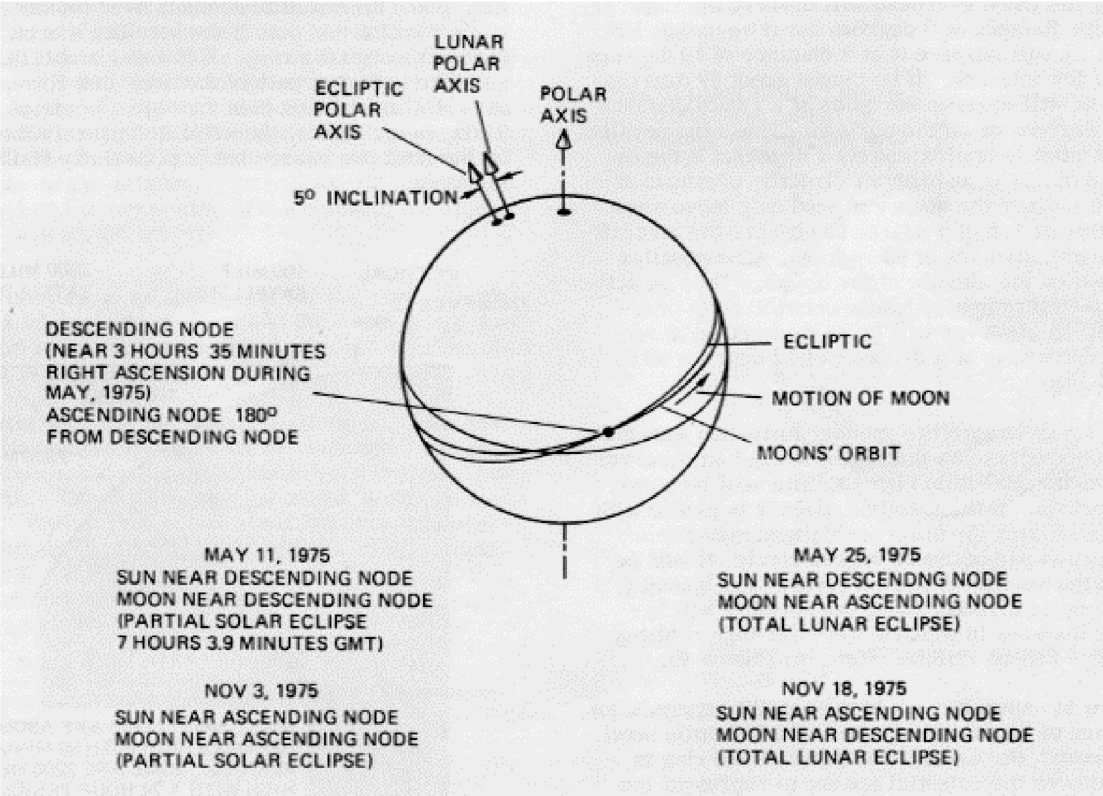


Figure 38. Characteristics of the Lunar Orbit

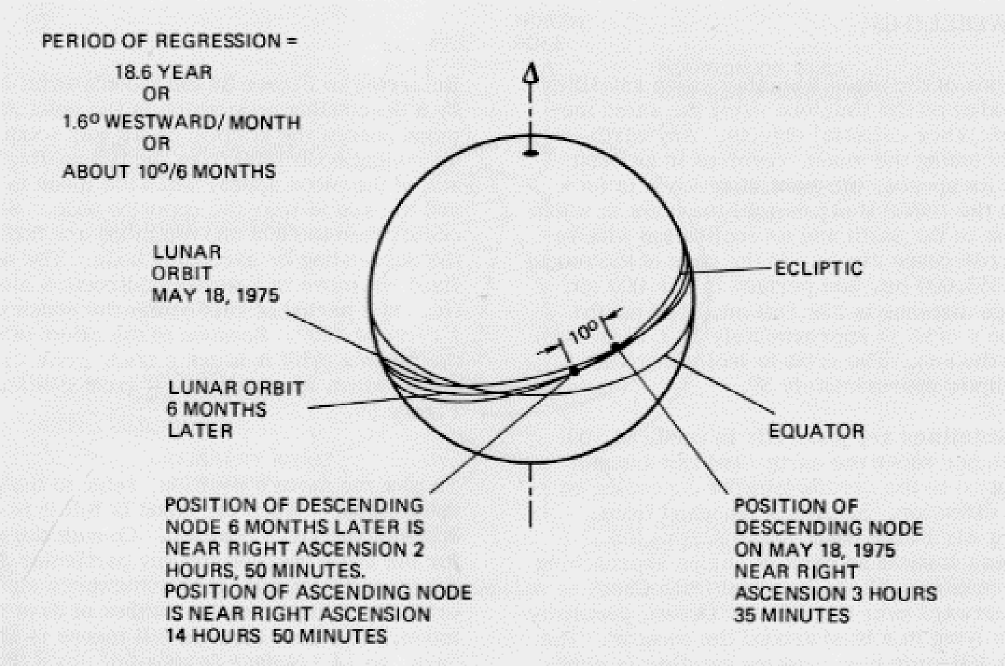


Figure 39. Regression of the Lunar Nodes

Earth satellites differ from other celestial objects in that they are much closer to the earth and the effect of parallax is pronounced. An observer seeing the moon overhead will observe the moon at a zenith distance of 0 degrees but if he moves 10° away, he will observe it a a distance of 10° plus a few minutes. If he moves about 89° away he will observe the moon at a zenith distance of 90° or on the horizon. Thus, the parallax of the moon is approximately 1 degree. If the observed object is an aircraft directly overhead at 1 mile altitude the observer need only move about 10 miles or 1/6 of a degree to observe the aircraft at a zenith distance of 90°. The parallax depends on the altitude of the object. Thus an artificial satellite in a 100 mile high orbit directly overhead to an observer will be on the horizon to an observer who is at a distance of 12° or 72 miles away.

The 12° satellite spanner furnished with the Uniglobe represents the region around an observer for which a 100 mile high satellite will be above the horizon. If the satellite spanner is placed with its center over the observer's position and the satellite is within the 12° circle, it will be above the horizon of the observer. The spanner, when placed directly under the satellite will indicate the area in which a 100 mile high orbiting satellite will be visible. Refer to Figure 40.

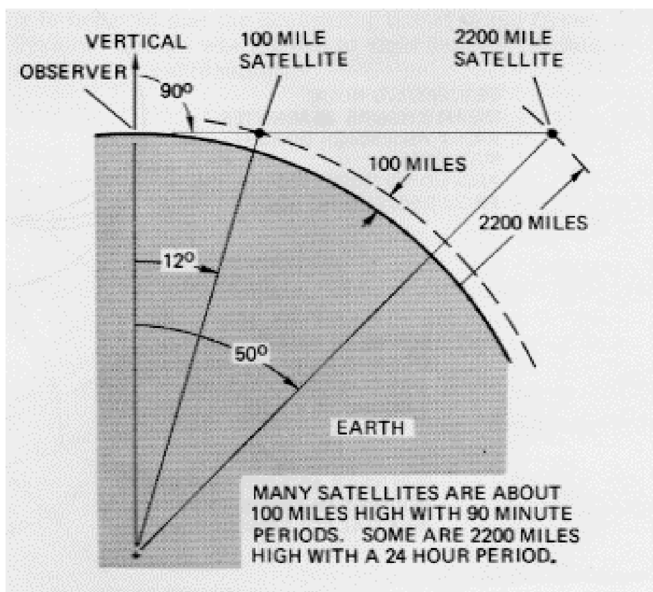


Figure 40. Visibility Regions of Earth Satellites

Figure 41 shows the use of the satellite spanner for a series of consecutive passes of a 100 mile high satellite around the earth. The great circle ring is placed over the celestial sphere to represent the satellite orbit. The earth globe is then rotated holding the celestial globe fixed. To determine when the satellite is visible, place the satellite spanner over the satellite's position in the orbit. To determine if an observer can sight the satellite, place the satellite spanner over the observer's position and note if the satellite's orbit passes through the ring. If it does, and if the satellite is in that part of the orbit that lies within the satellite spanner then the object is visible. Thus, in the figure, the satellite is not visible on the first two passes but is potentially visible on the third.

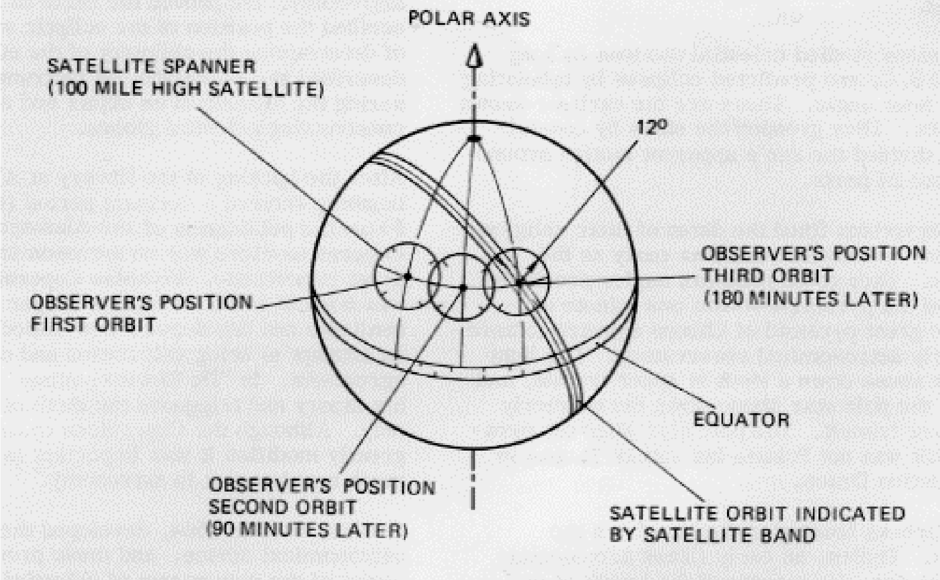


Figure 41. Visibility of a Specific Satellite Through Three Orbits

DETERMINING ASTROLOGICAL DATA

The Uniglobe is an ideal representation of the positions of the sun, earth and planets at the time of one's birth. To determine the birth sign, place the sun in its position on the ecliptic for the date of birth. The sun will fall into one of the zodiacal regions on the ecliptic. The equinoctial birth sign is read on the lower side of the ecliptic; the sidereal birth sign on the upper.

Determine from an ephemeris for the year of birth the positions of the planets and the moon at the time of birth and plot their positions on the Uniglobe. The result is a birth chart.

To determine the rising sign, orient the earth and celestial globes for the time of birth and mark the position on the celestial globe directly over the place of birth. This determines the zenith direction at birth. Position the spanner rosettra over this position and extend it eastward to intersect the ecliptic at the 90° point on the spanner cursor. The zodiacal zign at the intersection is the rising sign. See Figure 42.

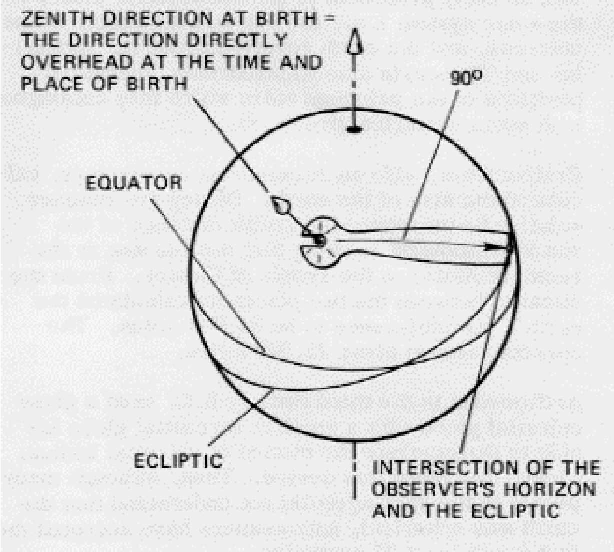


Figure 42. Determining Rising Sign

HISTORICAL NOTES

The science of astronomy is perhaps the oldest of the sciences. The first maps were probably of the heavens, since men used the movements of the moon, the sun, and the stars as guides in hunting, fishing, and farming.

The Babylonians studied celestial motions as long ago as 3,800 B.C. and predicted eclipses by tabulating the moon's hour angle. These are the earliest known ephemerides. They grouped the stars by constellations and divided the sun's apparent motion around the earth into 24 parts.

The early Egyptians fixed the dates of their religious festivals astronomically nearly as early as the Babylonians. They could measure angles precisely and oriented the pyramids within one minute of north. The great pyramid of Cheops appears to have been an early astronomical observatory. The light from Sirus shone down a shaft at upper transit., and the light of the pole star shone down the northerly shaft at lower transit. The pole star when the pyramid was bulit was not Polaris but rather Thuban in the constellation Draco.

The early Greeks learned navigation from the Phoenicians. Thales, an early Greek astronomer, was a Phoenician. He measured the length of the year and observed that the sun does not move uniformly between solstices. He is most famous for predicting the solar eclipse of 585 B.C. which ended a battle between Medes and the Lydians.

Aristarchus of Samos of the Alexandrian school who lived in the 1st half of the 3rd Century B.C., was an early proponent of the heliocentric theory of the solar system, i.e., the sun was the center of the universe and the earth revolved about it. Aristyllus and Timocaris, also Alexandrians, measured positions of the principal stars which they catalogued with some numerical precision.

Eratosthenes, also an Alexandrian astronomer, calculated the size of the earth. During the summer solstice he measured the zenith distance of the sun at Alexandria knowing that the sun was in the zenith at Aswan on the Tropic of Cancer. From the distance between the two places he calculated the earth's circumference to be 24,000 miles. The correct value is about 25,900 miles.

Archimedes in the third century B.C. used a glass celestial globe with a smaller terrestrial globe inside to demonstrate the motion of celestial bodies. Cicero described this device. Thus, although many people in the dark ages did not understand that the earth was spherical, astronomers have accepted the fact for at least 25 centuries.

Hipparchus, who was born in 180 B.C. was the greatest of the early astronomers. Unfortunately, he rejected the heliocentric theory of Aristarchus. He compiled a catalogue of more than 1,000 stars, giving their coordinates and divided them into six groups on the basis of brightness. By comparing the positions of these stars with the catalogue of Timocasris and Aristyllus of 250 years earlier, he calculated the precession of the equinoxes and defined the sidereal year and the tropical year.

Ptolemy, who chronicled the work of Hipparchus, lived between 100 and 200 A.D. he wrote the Almagest, a work of 13 books covering all Greek astronomy. He proved the earth to be round, described the position of the ecliptic and two methods of determining the obliquity of the ecliptic. He described the Astrolabe, an instrument for measuring the altitude of an object and a method for constructing celestial globes.

After the burningof the library at Alexandria, astronomy entered a dormant period (476-1500 A.D.). From the publication of the *Alamagest* to the time of Copernicus there was no astronomical discovery of great importance. Nicholas Copernicus, a Pole, was born in 1473. He was a lawyer and a doctor of medicine and developed a new heliocentric theory oin an attempt to bring calculation and observation into agreement. In *De Revolutionibu*s he presented his theory and triggered the birth of modern astronomy. Although the Copernican theory has been greatly modified it was important in that it spurred much new interest in astronomy.

Galileo, born in 1564, developed the telescope as an astronomical device and made precise measurements of the movements of celestial bodies. Galieo also developed the fundamental notions of mechanics upon which Newton later developed his theories. Tycho Brahe, the great Danish astronomer, designed and used special instruments to make precise observations which became the basis for much of Kepler's work. He also developed the sextant.

Johannes Kepler, born in Germany in 1571, worked with the observations of Tycho Brahe and Galileo to evolve his three basic laws of motion of the planets. He determined that the planets moved in elliptical paths about the sun.

Two contemporaries of Copernicus, Casper Vopal and Christian Hayden, designed armillary spheres to display information about the sky. Vopel, in 1500, made an armillary sphere with the earth in the center. Hayden, professor of mathematics at Nurenburg amde a brass shell with a celestial globe on the interior and a terrestial globe on the exterior.

The Gothorp globe, designed by Olearius in 1654, was 11 feet in diameter. It has a terrestrial map on the outside and a celestial map on the inside and a 15 cem. terrestrial sphere supported in the center.

Isaac Newton, born in 1643, developed the first theory of gravitation and a new system of mathematics, the calculus, with which he developed his theory. He derived from his theory the three basic laws previously propounded by Kepler.

Albert Einstein announced his special theory of relativity in 1905 and his general theory of relativity in 1915. He predicted from his theory of gravitation new laws of motion which have been confirmed through observations. His new theory of gravitation has explained minute discrepancies between the observed motions of the planets and those predicted by Newton's theory.