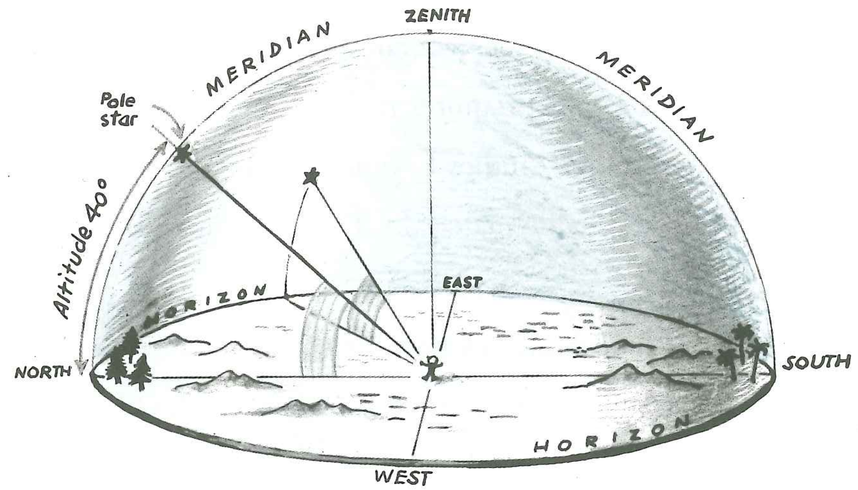


Figure 10: The Sky We See: A Half Globe

We shall start simply with what we see. We see the earth—if our view is unobstructed—as a flat, circular disc. The border of this disc is the horizon. We are in the exact center of it (no matter where we go, we are always in the center of "our" horizon). Over us we see the sky, a vast hollow half-globe, the rim of which sits on the horizon.

Figure 10 is a model of this setup. In the center of the disc is a Lilliputian observer. Throughout this project, imagine yourself in his shoes and visualize what he sees. Suppose our model represents the sky as seen from a place 40° latitude north, then the observer sees the Pole Star about[1] 40° above the horizon, due north. The distance of a star from the horizon is called its ALTITUDE. The Pole Star, therefore, has an altitude of about 40°. The altitude of the other star on this figure is about 25°. As a star wanders across the sky—or appears to be wandering—its altitude changes. The Pole Star's altitude however remains nearly the same unless the observer moves to a different *latitude*. The Pole Star's or, more exactly, the celestial pole's altitude always equals the observer's latitude. We shall find out *why* on page 116.

The (imaginary) line which the observer can draw from the north point on the horizon, through pole and zenith and down on the other half of the sky dome (the southern half) to the south point on the horizon, is the MERIDIAN, an important line, as we shall see.

A line from observer to celestial pole marks the axis around which we must make the model sky turn so that the observer sees his sky rotate, from east to west.

We realize at once that a *half-globe* will not do. If we set it turning around the axis, a gap would appear on the east side, and part of the half-globe would slide below the horizon on the west side.

We overcome this difficulty if, instead of a half-globe, we use a *full globe*. The observer inside sees only the globe's upper half, of course. The other half is underneath the ground he is standing on, below the horizon. We now prolong the axis underneath the disc; it pierces the disc in the

[1] If the Pole Star were *exactly* on the north celestial pole, its altitude at latitude 40° would be *exactly* 40°. The Pole Star is about 1° off the true pole but we may neglect this small difference in the present demonstration.

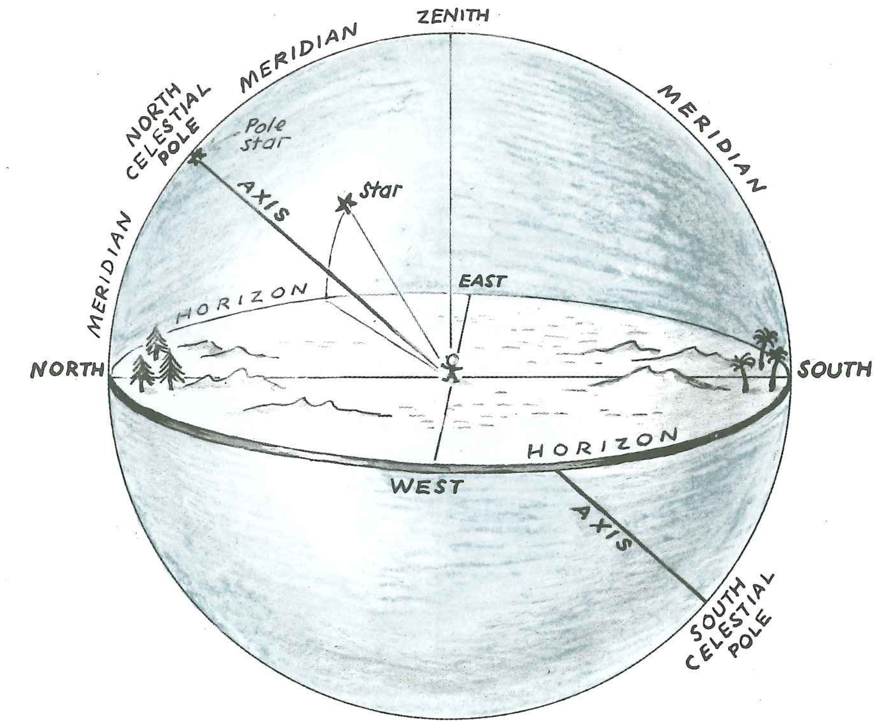


Figure 11: The Sky as a Full Globe

center, where the observer is, and meets the lower half of the globe at a point exactly opposite the north celestial pole: the *south celestial pole.* While the globe turns around this axis, the position of the disc in the globe remains unchanged: it does not move, only the surrounding sky does, as the observer sees it.

If stars are attached to the globe, and the globe rotates, what does the Lilliputian observer see from the center of our miniature planetarium?

To keep things simple we will consider just one star, the one we saw on the previous picture, about 25° above the northeastern horizon. On the next figure we shall have a look at the course which the observer sees the star describe as the globe rotates.

NOTE: It took mankind a long time to conceive the sky as a full globe. The Greeks seem to have had this idea first. Our friend from Chaldea—whom we are now leaving far behind—thought that the stars, and also the sun, moon, and planets, moved across the vaulted sky overhead, from east to west, and then crawled back along the flat underside of the earth disc, to rise again over the eastern rim of the disc, in due course.

On the other hand, we must keep in mind that the sky globe is not a *real* globe in the sense that the earth is. Strictly speaking there is no such thing as a sky, only stars on a background of void. Yet the sky globe is neither an arbitrary assumption nor an optical illusion. We actually see one half of the hollow globe at any moment, with the other half unseen but coming into sight as the sphere appears to rotate. The sky globe has no size expressible in miles or square miles. We can call its diameter infinite or indefinite if we like; it does not matter much; we don't use the diameter as a measuring unit as we do on solid spheres. Instead, distances on the sky are measured in degrees (from horizon to zenith is 90°, once around the horizon 360°)—and surfaces, in square degrees.

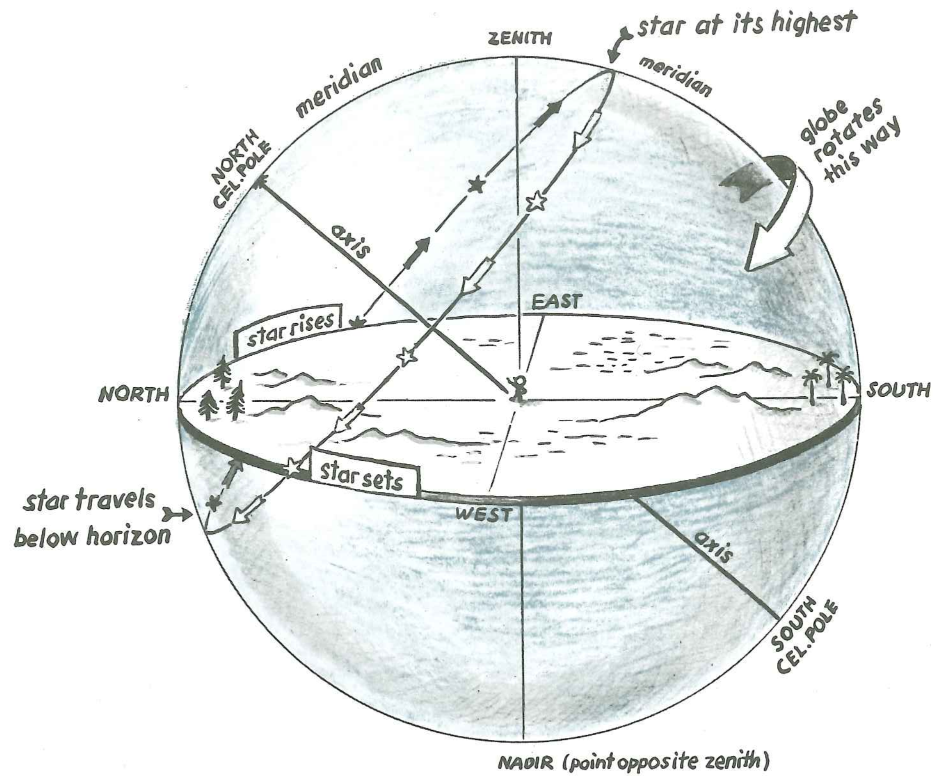


Figure 12: The Sky Globe Rotates

As the globe slowly rotates from E to W, the observer inside sees the star move upward at an angle. At its highest point it is exactly on the *meridian,* and after crossing the meridian it descends slowly on the western half of the sky. It goes down with the same slant as when it rose, only in the opposite sense, and sets below the western horizon. For a while, as the globe goes on turning, the star travels below the horizon and the observer cannot see it until it rises above the eastern horizon.

The points of rising and setting are equally far away from the horizon's north point. If a star rises, say, due NE, it sets due NW; if it rises SE by E, it sets SW by W, and so on, and any star (but not sun, moon, and planets) always rises and sets at the same points (seen from the same locality) throughout the year, only at different times.

All stars, and also sun, moon, and planets, are at their highest—they *culminate*—when they cross the meridian. When the sun crosses the meridian, we have *noon* (*meridian* from Latin *meridies,* noon). The average time span from one noon to the next is a day[1]—the ordinary day we all live by. But to the astronomer this is not just a day but a SOLAR or SUN DAY (from Latin *sol,* sun). He also has the SIDEREAL or STAR DAY (from Latin *sidus,* star): the time span, very nearly,[2] between two successive culminations of a star. From one culmination to the next the star makes a full turn—apparently. In reality the earth does the turning, and the sidereal day is therefore, very nearly, the period of the true rotation of the earth in relation to the stars.

The sidereal day is about four minutes shorter (the four minutes mentioned on page 66) than the solar day, and its subdivisions: sidereal hours, minutes, seconds, are proportionally shorter than solar hours, minutes, seconds. We shall see the reason for this difference on page 122.

[1] We count our days from midnight to midnight, though. Otherwise we should have to change dates every noon, and lunch might begin on Tuesday and end on Wednesday.

[2] Very nearly because the sidereal day is measured not by the culminations of a *star* but by two successive culminations of the *vernal equinox* (see figure 19) which is not stationary but moving slowly. The difference is very small—0.008 second a day, or one day in 25,800 years—and results from the "wobble" of the earth's axis, described on page 128.

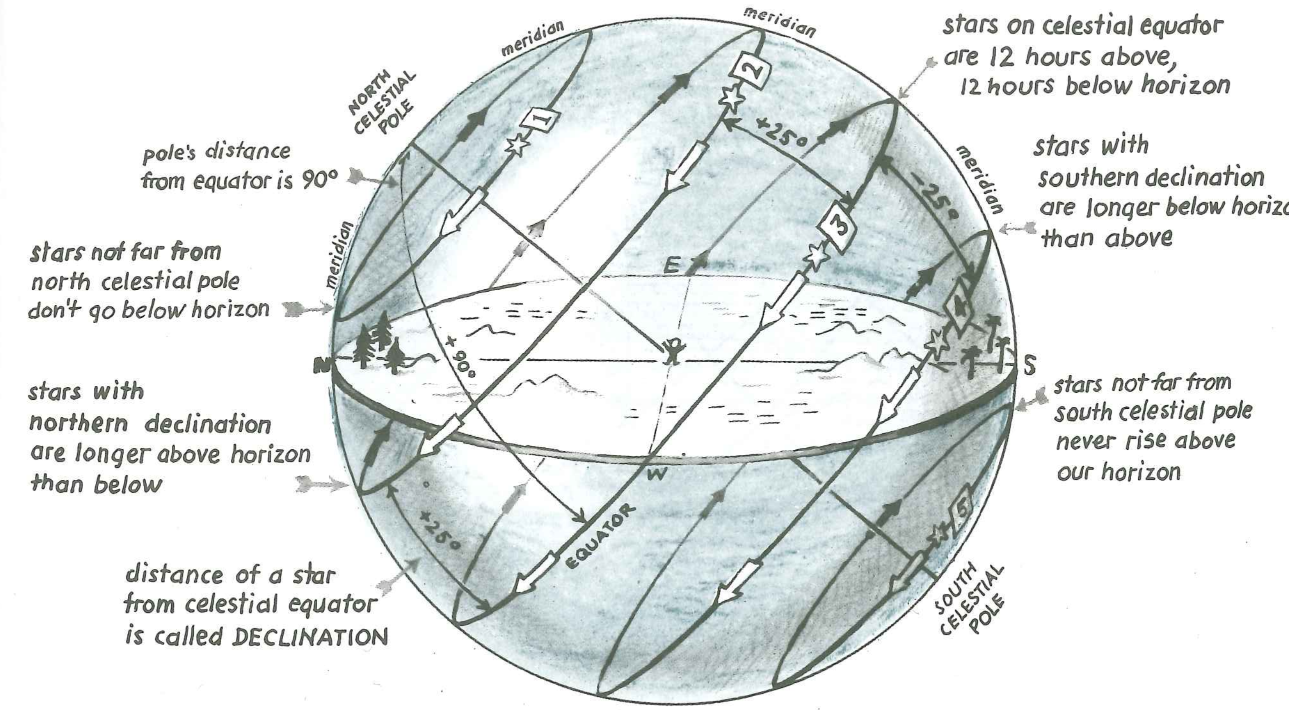


Figure 13: Parallels of Declination

We now attach a few more stars to the rotating globe: star 1 not far from the north celestial pole; star 2 somewhat farther away; star 3 halfway between north and south poles; star 4 closer to south pole than to north pole; and star 5 not far from the south pole.

The observer inside the globe sees *star 1* circle around the north pole without ever going below the horizon. *Star 2* goes below the horizon for a while but is longer above the horizon than it is below. *Star 3,* halfway between the two poles, is half the time above the horizon, half the time below. Since one rotation takes 24 (sidereal) hours, this star is visible 12 hours. It rises due east and sets due west. *Star 4,* rising about southeast and setting southwest, spends more time below the horizon than above; and *star 5,* close to the south celestial pole, does not rise above the horizon at all; the observer never sees it.

The lines which mark the paths of the five stars are parallel. They look very much like circles of latitude, or parallels, on a terrestrial globe. In fact the celestial globe has such (imaginary) parallel circles; they are called PARALLELS OF DECLINATION. The particular circle which divides the celestial globe in two, into a northern and a southern celestial hemisphere, is called the CELESTIAL EQUATOR. Its declination is 0° (just as the earth's equator is latitude 0°), and the declination of each star is measured from there, in degrees. *Star 2* on the figure, for instance, has a declination of 25° north (written: Dec.+25°), while *star 4* has a declination of 25° south (written: Dec.—25°).

Since the celestial equator—and with it all the parallels of declination—always keeps its distance from the celestial poles, its place in the sky, for an observer, does not change unless the observer moves to a different latitude.

You can visualize the celestial equator any night if you can remember a few star groups which are on it or near it: Orion's Belt; Hydra's head; the Virgin; the Eagle's left wing tip; Water Carrier's head; the Whale's tail.

While the *altitude* of a star changes during the night, as the star rises or sets, its *declination* (distance from the celestial equator) *does not.* It tells where on the celestial sphere the star is to be found, at any time, but does not tell all. If we say a star has a declination of 25° north, it could be anywhere on the circle, 25° north of the celestial equator. Just as on the terrestrial globe, we must give the star's longitude. How this is done, we will see on the next pages.

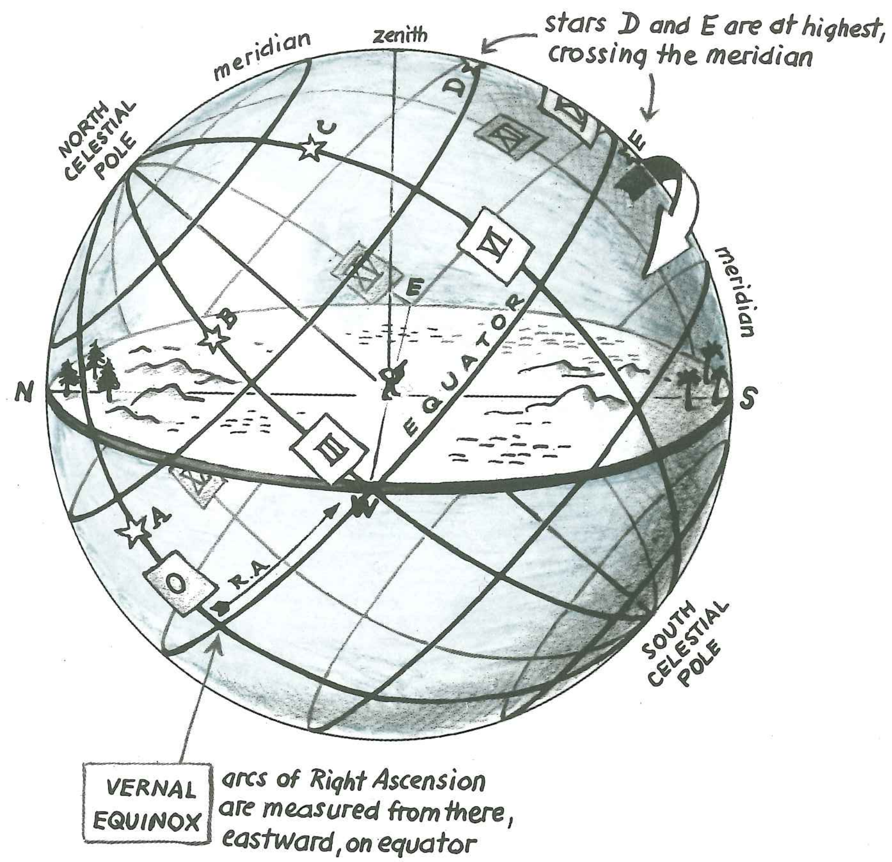


Figure 14: Hour Circles

What are circles of longitude on the terrestrial globe, are called *hour circles* on the celestial globe. The hour circle of a star is one half of a great circle going from north to south celestial pole, passing through the star. On our model the half-circle marked O is the hour circle of star A; star B is on the hour circle marked III; star C is on the VI hour circle, and D and E are on the IX hour circle.

There are 24 hour circles, from O to XXIII, and they are counted eastward on the celestial equator from a point in the *Fishes* called the VERNAL, or SPRING, EQUINOX (see page 119, figure 19). The hour circle going through this point is the ZERO HOUR CIRCLE. Each hour circle, being only one half of a great circle, has a counterpart which complements it to a full circle. To the zero hour circle this is the XII hour circle; to I hour circle, XIII hour circle; and so on: you can see it dimly on the sketch.[1]

As the sky rotates the hour circles rotate too. When an hour circle is at its highest it coincides with the meridian. At that moment all stars on that hour circle culminate. Stars on the same hour circle culminate at the same time (on the sketch, stars D and E are culminating) but, having different declinations, they do not rise and set at the same time. When the zero hour circle is on the meridian the *sidereal day* begins: it is O h sidereal time, a moment as important to the astronomer as midnight or noon is to the ordinary citizen. One (sidereal) hour after the O h circle has passed the meridian, I h circle passes it—at 1 h sidereal time; after another hour, at 2 h

[1] The hour circles are marked on the UNIVERSAL SKY CHART on pages 158–59 as well as on the star chart inside the jacket of this book.

sidereal time, II h circle passes the meridian, and so on. After twenty-four sidereal hours, O h circle passes the meridian again and a new sidereal day begins.

Hour circle and parallel of declination define the place of a star on the celestial globe, as longitude and latitude define a place on earth. But instead of writing "hour circle" the astronomer usually gives the RIGHT ASCENSION (R.A. for short) of a star. This is the arc, on the equator, measured eastward from the vernal equinox to the point where the star's hour line crosses the equator. It is expressed in hours, minutes, and seconds. A star on Hour Line XIX has R.A. 19. The full "address" of a star—say CAPELLA—reads: R.A. 5^h13^m Dec.+45°57′ ("Dec.+" = North Declination). This not only tells you the star's place among its companions, but also that it culminates at 5^h13^m sidereal time every day and that, being halfway between pole and equator, it is visible most of the time in our latitudes.

On the foregoing pages, we referred to the fact that the pole's altitude equals the observer's latitude; that the hour circles are measured from the vernal equinox (which is one of the two points where the ecliptic—the sun's apparent path—crosses the celestial equator); and that the sidereal day is about four minutes shorter than the solar day, but we did not explain those facts nor describe the elements involved.

We shall do this now, and in connection therewith have a look at the zodiac; at the causes for our seasons; and at the shift of the celestial poles through the ages caused by the "wobble" of the earth's axis.

In addition, let us briefly consider planets and moon, as well as the galaxy of which our solar system is an infinitesimal part. We shall conclude with a quick glance at the history of the constellations and at the possibilities of life outside our earth.

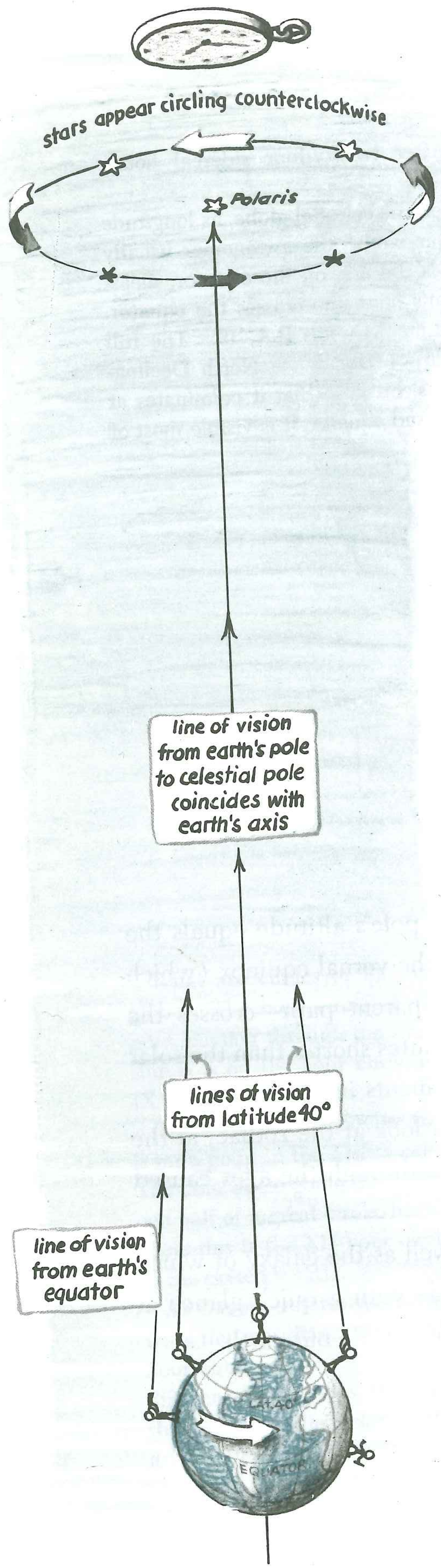


Figure 15: Pole Star and Latitude

POLE STAR AND LATITUDE

Ours is an age of travel. Thousand-mile trips are trivial affairs, and many a stargazer has an opportunity to watch the skies change as he journeys north or south for any great distance. The shape of the constellations remains of course unaffected but he finds that, say, in southern Florida Polaris stands quite low, about 25° above the horizon, and he sees some constellations he did not see when a few days ago he looked at the stars from northern Minnesota, where he saw the Pole Star more than half way up toward the zenith.

To put it precisely (as stated on page 110): the altitude of the celestial pole equals the observer's latitude. The altitude changes as the observer moves north or south, and the *axis around which he sees the whole star sphere turn appears less or more tilted according to his higher or lower latitude.* This fact permits him to determine his latitude by watching the stars. It is an important fact, but so far we have not explained it. So here is why.

On figure 15 we have the earth with an observer standing at the earth's north pole and looking at Polaris through a telescope. The Pole Star, true, is not exactly on the celestial pole but we can neglect the small difference for a moment. Since the celestial pole is the point to which the earth's axis points, he must look up vertically to see the Pole Star. As the earth under him turns from west to east, the stars around Polaris are circling around the pole, so it seems to him, counterclockwise; Polaris itself remains in its place, or nearly.

But if he moves away from the earth's north pole, Polaris is no longer overhead. The farther south he goes the farther down must he tilt his telescope to look at it, and if he moves to the earth's southern hemisphere Polaris will sink below his horizon.

That much we see from the picture.[1] We also see that, as long as the observer remains on the same parallel—say, the 40th—the tilt of his telescope remains the same as he looks at Polaris, and this goes for all circles of latitude, including the equator.

[1] The sinking of the Pole Star as the observer moves southward is hard to visualize for some, although it is easy to comprehend in geometrical terms. This may help you: tilt the page slowly so that the little man, first on lat. 40°, then on the equator, comes to stand upright, and watch Polaris all the while: you can actually see it sink lower and lower from its overhead position, as you tilt.

But we cannot see from figure 15 what exactly the tilt has to be, on a given latitude, because on the scale of this drawing with a one-inch earth, Polaris would have to be many miles away instead of a few inches, and all lines of vision, from any point of this small earth, to the celestial pole would be practically parallel (as they are in reality) instead of slightly converging, as on that drawing.

We therefore need a new drawing (figure 15A) where all lines of vision from different latitudes are parallel to the earth's axis which, as we know, coincides with the line of vision from the terrestrial to the celestial pole (axis of the celestial sphere). Now the Pole Star's or, more accurately, the celestial pole's altitude is the angle between the observer's line of vision to the celestial pole and the plane of the horizon, from any given point. If all lines of vision, from anywhere, are parallel, all we have to find out is: at what angle do they meet the plane of the horizon at given latitudes, keeping in mind that the plane of the horizon at any point on earth is perpendicular to the earth's radius at that point. (We may consider the earth as a perfect sphere in this demonstration and disregard its slight flattening at the poles.)

The latitude of a point being the angle between earth's radius and plane of equator, and its complement being equal to the altitude's complement (50° in our case) because both are on parallels, the two angles, latitude and altitude (colored blue on the sketch), are also equal; which is what we set out to show.

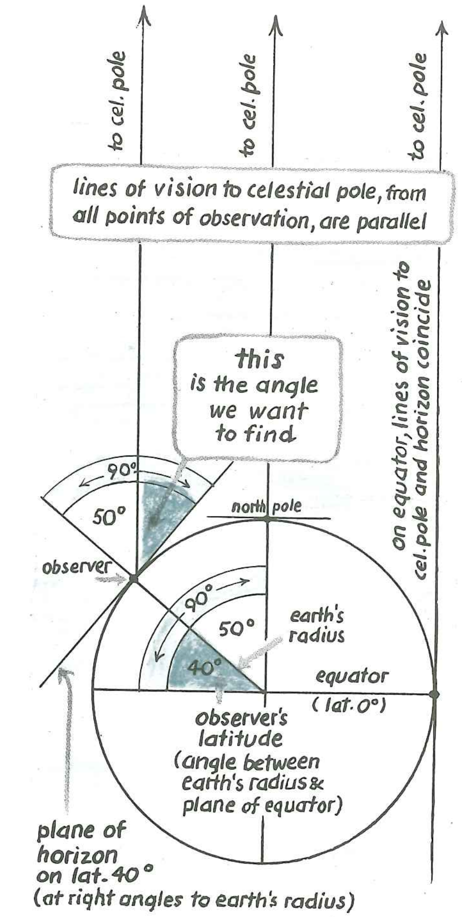


Figure 15A: The Pole's Altitude

Here are three examples illustrating the tilt of the sky sphere at different latitudes:

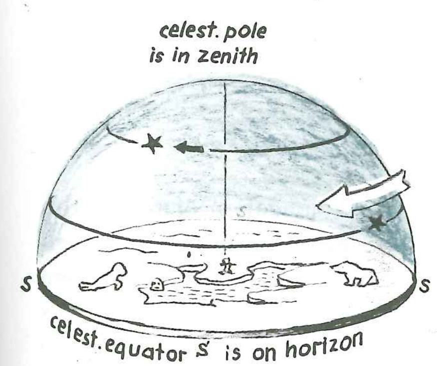


Figure 16

The Sky at the North Pole

Only northern half of celestial sphere visible at any time. Stars circle around pole parallel to horizon, don't rise or set. There is no east or west; all directions are south. Stars south of celestial equator permanently out of sight.

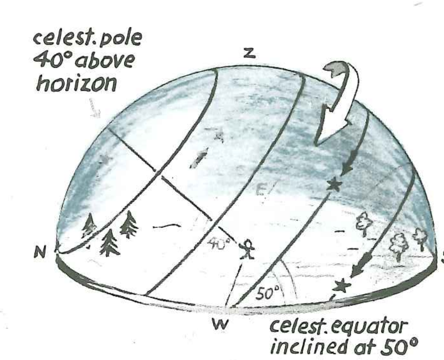


Figure 17

The Sky at 40° Latitude North

Axis of celestial sphere tilted at 40°. Stars north of celestial equator longer above horizon than below. Many, but not all, stars of south celestial hemisphere visible but below horizon longer than above. Celestial equator inclined 50° (R-40°) against plane of horizon.

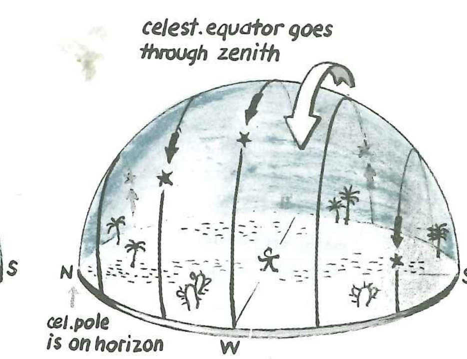


Figure 18

The Sky at the Equator

Axis of celestial sphere lies on plane of horizon. Pole Star on horizon (nearly). Exactly half of either celestial hemisphere—northern and southern—visible at all times, with celestial equator passing through zenith. Stars rise and set vertically, and all stars in entire sky can be seen at one time or another.

ECLIPTIC AND SEASONS

The figure on the opposite page shows the earth and its ORBIT (its yearly course around the sun) inside a large hollow globe representing the celestial sphere. Marked on the sphere are the Pole Star, the axis of the celestial sphere, the celestial equator, and the zero hour circle which we discussed on page 114. Around the sphere, at an angle to the equator, runs a belt, here drawn in lighter color, with 12 constellations marked on it. This belt is the ZODIAC (we shall consider it on page 130), and along its middle runs a broken line, the ECLIPTIC—the apparent path of the sun among the stars in the course of a year.

A closer look at the drawing shows how this apparent path comes about:

The earth on its yearly course is shown in 4 positions: December 22, March 21, June 21, and September 23. As you study the model you can see how to an observer on the earth the sun would appear against a different background of stars as the earth proceeds along its orbit while the sky with its stars remains unmoved. (No misunderstanding: on this model we are not considering the *apparent daily motion of the sky* seen from an earth at rest, but the *real yearly motion of the earth* against a sky at rest.)

Now suppose an observer on the earth were in a balloon in the upper stratosphere where sun and stars are visible at the same time; he would see the sun against the *Archer* as background in December; against the *Fishes* in March; it would appear in the *Twins* in June, and in the *Virgin* in September; the following December it would be in the *Archer* again, and so on.[1]

If he plotted the sun's position among the stars from day to day on a star globe of his own, he would see it drift eastward by almost 1° daily (360° in 365¼ days) and after a year he would have plotted a great circle line around his globe, the same as on our drawing: the *ecliptic*, so called because eclipses of sun and moon occur along that line.

Now the earth not only revolves around the sun, it also turns around itself all the time, causing day and night. For reasons unknown even to the experts, it so happens that the *axis around which the planet turns does not stand perpendicular to the plane of the orbit,* but deviates from the vertical by 23½°.

If this were not so, if the axis stood vertical, day and night would be equal everywhere throughout the year, and there would be no seasons. Besides, figure 19 would look simpler and we would have nothing more to explain here. But since there *is* such a tilt, we do have a change of seasons and of the day's length, and an explanation is called for. So here it is:

The earth's axis being thus tilted, and the celestial axis being but the prolongation of the earth's axis, the celestial axis is tilted by the same angle, 23½°. The celestial equator, in turn, being perpendicular to the celestial axis, is inclined against the ecliptic by 23½° also, as figure 19 shows. The two great circles, equator and ecliptic, intersect in two points, opposite each other (marked by arrows on the drawing), and one half of the ecliptic (where the *Twins* are) is above, that is north of, the equator, while the other half (the *Archer* half) is south of it.

When the sun, on its yearly course along the ecliptic, reaches either of the two points of inter-

[1] Those of us not in possession of stratosphere balloons cannot see the constellation the sun is in, at a given moment, because the sun blots it out. But we can always tell by watching the sky at night: the constellation crossing our meridian at midnight is opposite the one the sun is in at the moment, and our model shows roughly which is opposite which.

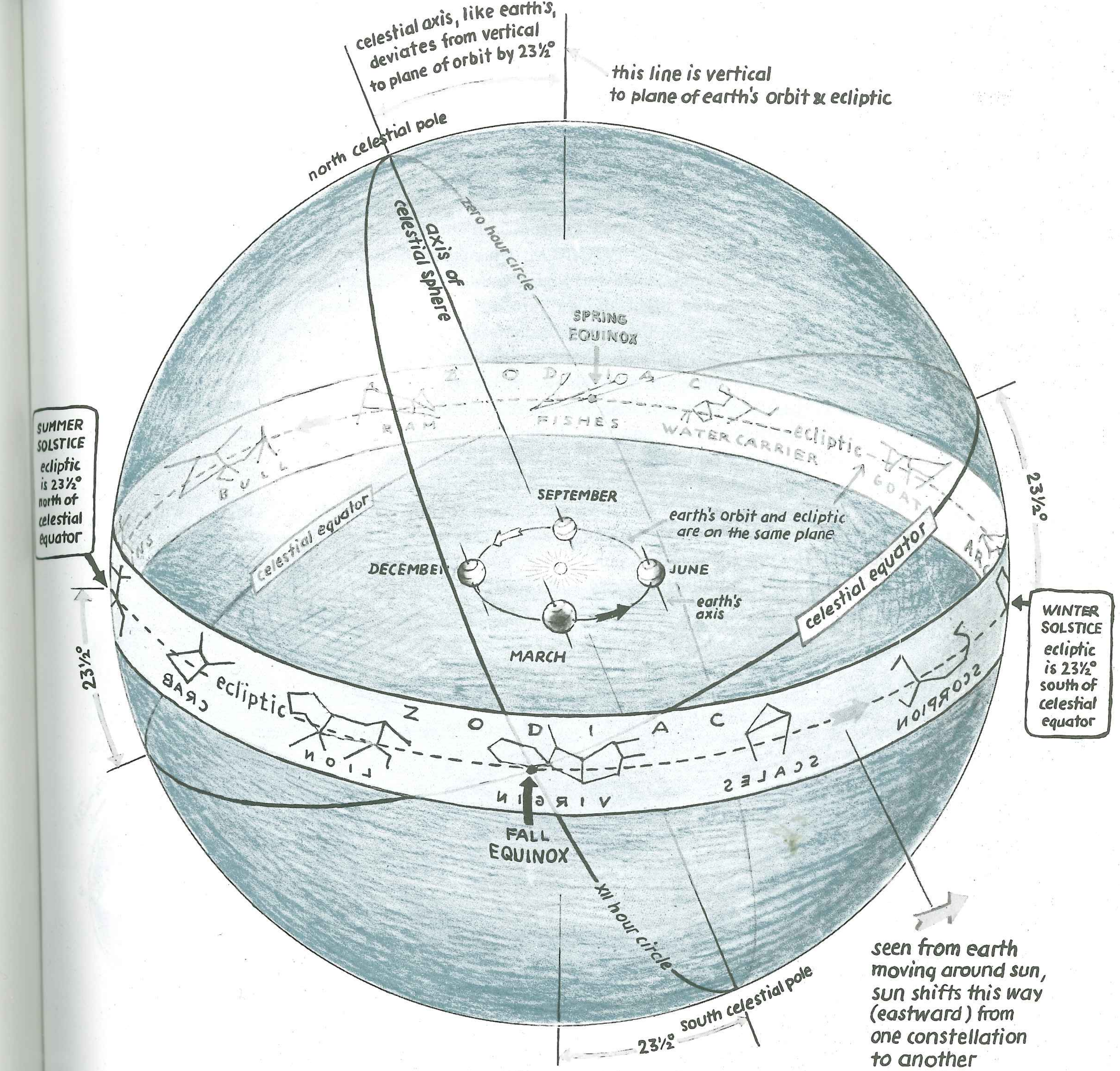
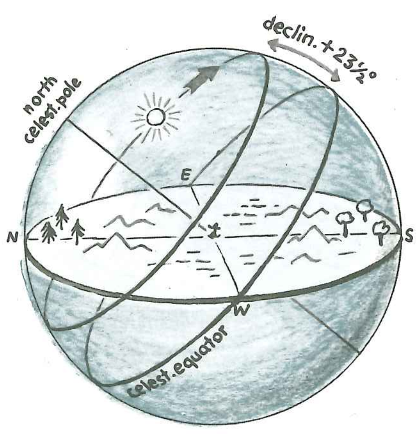


Figure 19: Earth's Orbit inside Celestial Sphere

As on all our models, proportions on this one are not drawn to scale. Sun is too small, earth too big, and sky globe much too small in relation to orbit. Pole Star on sky globe's top ought to be many miles away, so that earth's orbit, including sun, shrinks to a pinpoint in comparison with globe. The four separate axes piercing the tiny earth globes on our model would melt into one, and practically coincide with the celestial axis, as is the case in nature. Such inaccuracies are unavoidable but, once explained, become irrelevant.

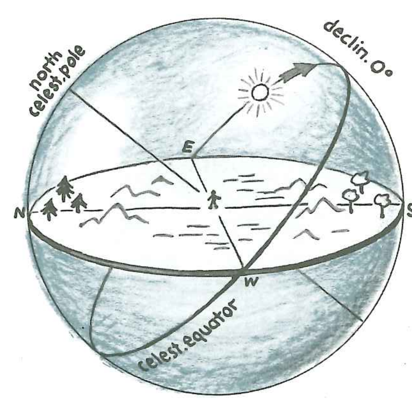
section, it is, for that moment, on the equator. As we saw on page 114, stars on the celestial equator are above and below the horizon 12 hours each, and the same goes for the sun as it crosses the equator. At those points day and night are of equal length, and they are therefore called EQUINOXES (from Latin *aequus*, equal, and *nox*, night), one being the VERNAL (from Latin *ver*, spring) or SPRING EQUINOX, when the sun is in the *Fishes;* the other, the AUTUMNAL (from Latin *autumnus*, fall) or FALL EQUINOX, when the sun is in the *Virgin*. This happens on or about March 21 and September 23 and marks the beginning of spring and fall.

The rest of the year, however, night and day are not equal, and this is what happens: as the sun appears to drift eastward along the ecliptic from, say, the *Fishes* toward the *Ram*, its distance from the celestial equator (that is, its northern declination) increases, and it is longer above the horizon than below in the northern hemisphere. After one quarter of its yearly course, in the *Twins*, it reaches its greatest distance from the equator: its northern declination is 23½°: the day is longest, the night shortest. From now on, declination and day's length decrease. At the fall equinox, day and night are equal again. Thereafter the sun's declination becomes "minus," that is, southern: the sun spends more time below the horizon than above; days grow shorter, nights longer till, about December 22, the sun reaches that point of the ecliptic (in the *Archer*) which is farthest south of the equator; its declination now is —23½°. The day is now shortest, the night longest. This marks another turning point: from now on the days become longer, the nights shorter, and at the vernal equinox the yearly cycle starts again.



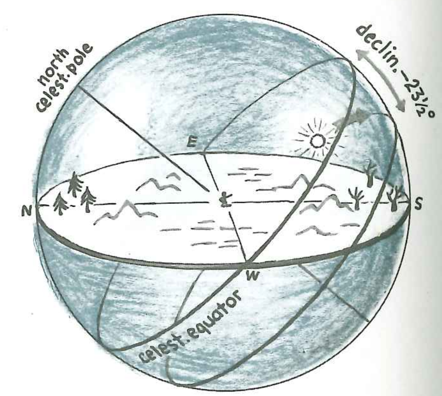
Sun's Course on June 21

Sun rises NE, sets NW, above horizon about 15 h. Sun is N of Equator.



Sun's Course March 21 and September 23

Sun rises E, sets W, above horizon 12 h. Sun is on Equator.



Sun's Course December 22

Sun rises SE, sets SW, above horizon about 9 h. Sun is S of Equator.

Figure 20: Sun's Daily Course at Solstices and Equinoxes

The turning points, on or about June 21 and December 22, are called SUMMER and WINTER SOLSTICE (from Latin *sol*, sun, and *stare*, stand still), and the passing of the sun through the equinoxes and solstices marks the beginning of our four seasons.[1]

The apparent course of the sun across the sky seen from 40° north latitude on the days of solstice and both equinoxes is shown in figure 20.

How long the longest day and how short the shortest, depends on one's latitude. On the earth's equator, day and night are of even length throughout the year, but as one moves away from the equator—north or south—the seasonal differences appear and become the greater the closer one gets to the earth's poles. In our latitudes—about 40°—the longest day lasts about 15 hours, the shortest, 9 hours. Inside the polar circles, within 23½° of the poles, you have midnight sun in midsummer: the longest day lasts 24 hours and so does the longest night. And on the poles, night and day last 6 months each.

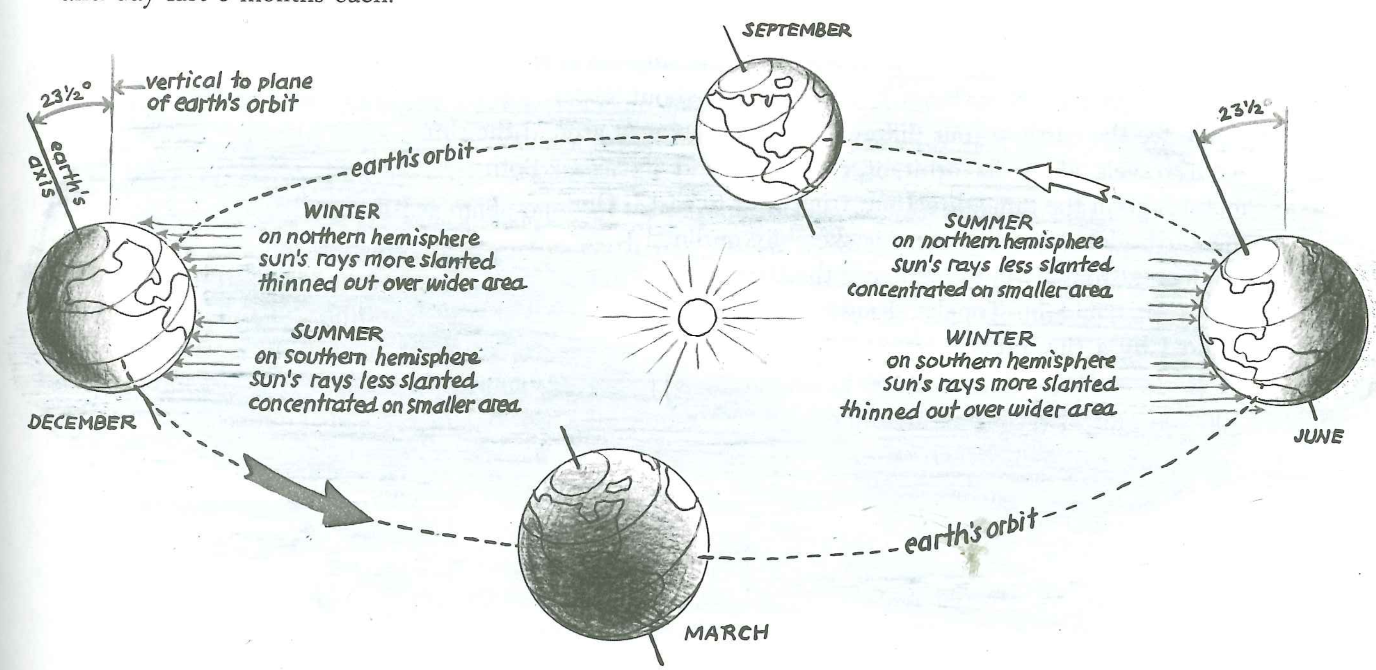


Figure 21: Tilt of Earth's Axis Causes the Seasons

Longer days and shorter nights, and vice versa, would alone explain why summer is warm and winter cold. But another fact, also resulting from the slant of the earth's axis, makes summers even warmer and winters colder: the angle at which the sun's rays fall on the earth at the different seasons.

As figure 21 shows, the sun's rays strike the earth at a much sharper slant in winter than in summer. The same amount of sunshine is thus thinned out over a greater area in winter than in summer, and besides the rays must penetrate a greater portion of the earth's atmosphere, and this dilutes their effect even more. It is true that not June, but July and August are our hottest months, and that September is warmer than March, but it is not the sun's direct responsibility; the heat stored up daily by the earth in summer, and lost daily in winter, accounts for that.

[1] The seasons of the southern hemisphere of the earth are the opposite of ours. When we have spring, people in the Argentine have fall, and when at Washington, D.C., the sun appears for little more than 9 hours, in mid-December, people in Melbourne, Australia, a corresponding southern latitude, see it for about 15 hours.

SOLAR AND SIDEREAL DAY

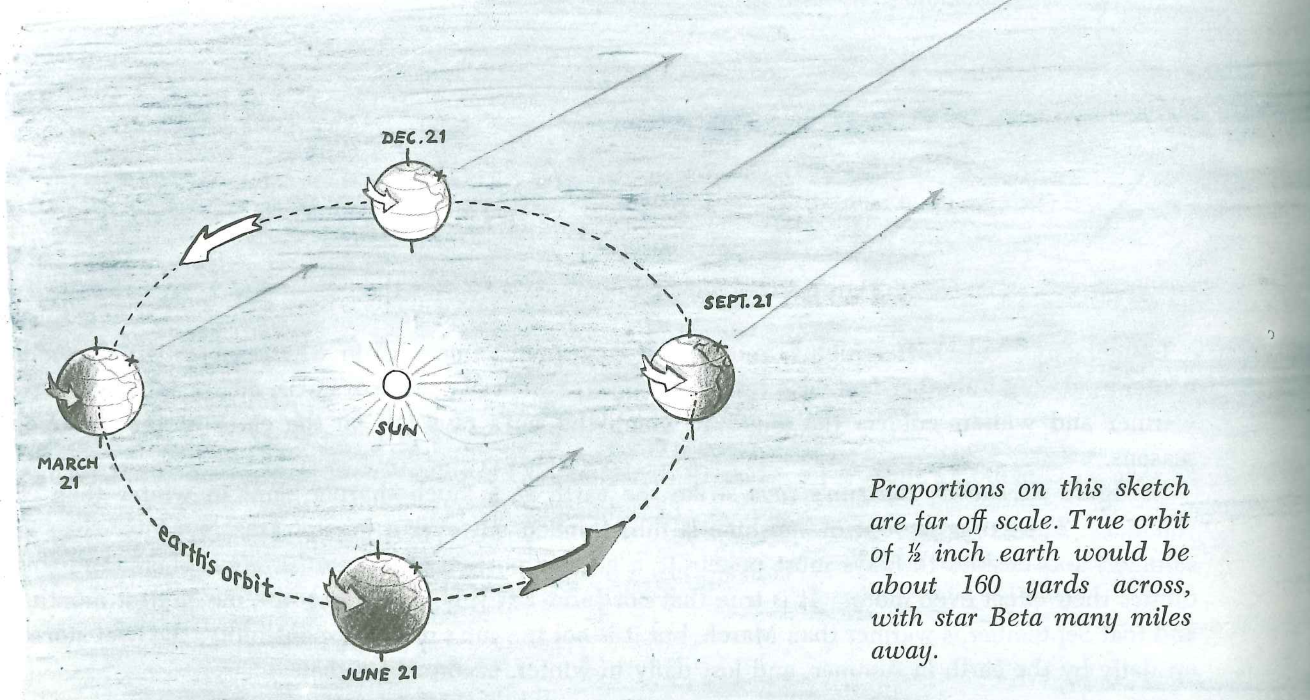
Anyone can find out, just by watching the sky, that the same stars culminate about four minutes earlier every day; in other words, that the sidereal day is about four minutes shorter than the solar day. But *observing a phenomenon* and *finding its reasons* are two things: we still have to *explain* this daily gain of four minutes which causes our skies to change through the year.

The *sidereal day*, the time between two transits of the equinox, is very nearly the time it takes the earth to make one complete turn around itself: the *time of the true rotation of the earth*, which causes the apparent rotation of the stars. We saw that on page 112.

The *solar day* is *not a measure of this true rotation*. It is, as we saw, the average time from one noon to the next; a place on earth has noon when the sun is in its meridian; when the place faces the sun, to put it graphically.

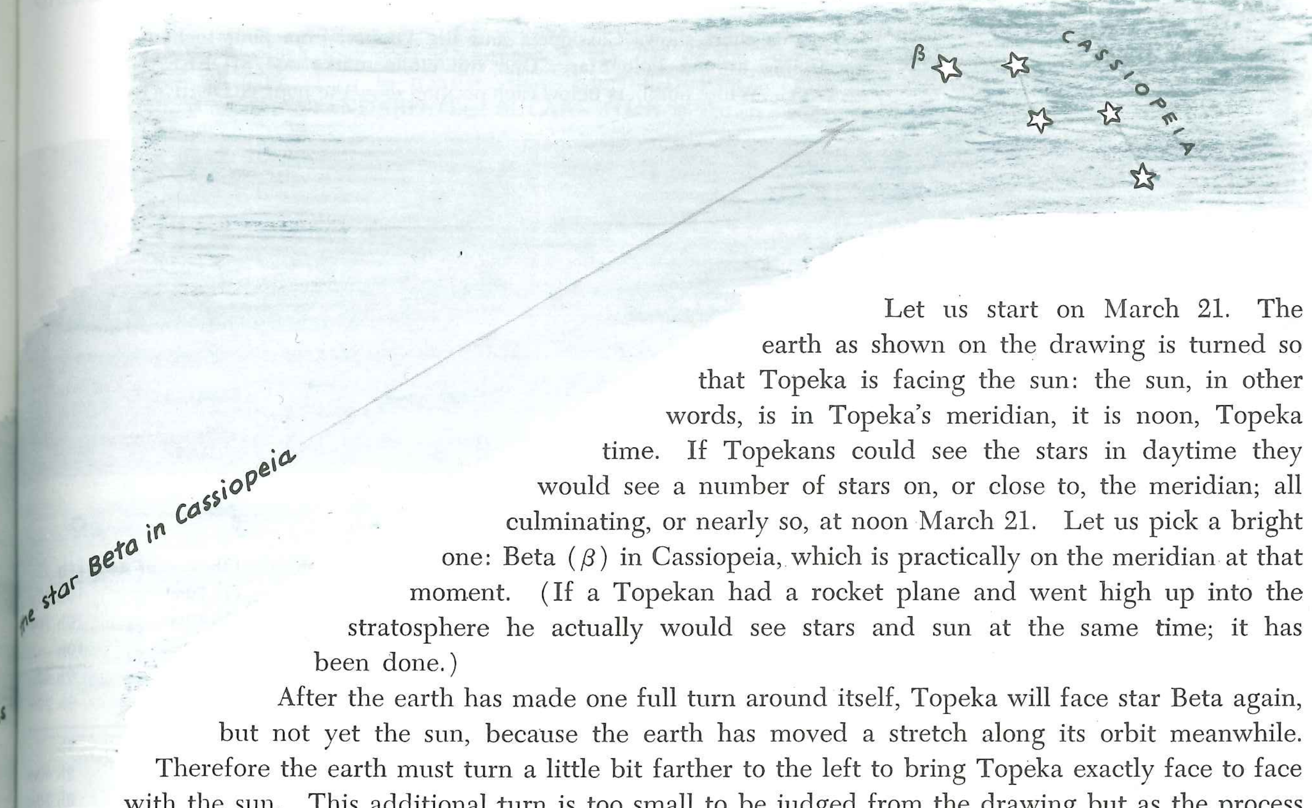
The two days, sidereal and solar, are not of the same length because the earth, while rotating around its axis, also travels around the sun. A careful look at figure 22 plus a bit of reflection shows how this comes about.

We see the earth at four different points on its way around the sun. As it travels along its orbit, it rotates around its axis. Both motions go in the same direction: from west to east. On the earth globe, our continent is sketchily outlined and a point roughly in the center of the United States—it could be Topeka, Kansas—is marked by a tiny cross.



Proportions on this sketch are far off scale. True orbit of ½ inch earth would be about 160 yards across, with star Beta many miles away.

Figure 22: Sun-Day and Star-Day through the Year



Let us start on March 21. The earth as shown on the drawing is turned so that Topeka is facing the sun: the sun, in other words, is in Topeka's meridian, it is noon, Topeka time. If Topekans could see the stars in daytime they would see a number of stars on, or close to, the meridian; all culminating, or nearly so, at noon March 21. Let us pick a bright one: Beta (β) in Cassiopeia, which is practically on the meridian at that moment. (If a Topekan had a rocket plane and went high up into the stratosphere he actually would see stars and sun at the same time; it has been done.)

After the earth has made one full turn around itself, Topeka will face star Beta again, but not yet the sun, because the earth has moved a stretch along its orbit meanwhile. Therefore the earth must turn a little bit farther to the left to bring Topeka exactly face to face with the sun. This additional turn is too small to be judged from the drawing but as the process repeats itself daily, the difference soon becomes striking.

To simplify our figures let us assume the year had 12 months of 30 days each: on June 21, after 90 true turns around its axis—that is, after 90 sidereal days—Topeka faces star Beta for the 90th time since we started. But now one can clearly see, even on this small sketch, that the earth must make a quarter turn to bring Topeka face to face with the sun for the 90th time. In other words, 90 solar days are not yet completed. Noon is 6 hours off, the time it will take the earth to make that quarter turn. It is 6 A.M. solar time; the star has gained 6 hours.

On September 21, after another 90 true rotations—180 sidereal days having passed in all—Topeka faces the star Beta for the 180th time, but not yet the sun. It faces in the opposite direction now, and a complete half-turn is necessary to bring the Kansan capital face to face with the sun: noon is 12 hours off. In other words, it is midnight, solar time, and the stars have gained 12 hours. On December 21, the difference is 18 hours, the earth has three-quarters of a full turn to make before it becomes noon at Topeka, and on March 21, the total gain is 24 hours—one complete rotation.

Gaining 24 hours in 360 days means gaining 2 hours a month, or exactly 4 minutes a day. Now our year has 365.24 solar days (but 366.24 sidereal days)—so the gain of 24 hours is spread over a few more days than we assumed above, and the *daily* gain, therefore, is a trifle smaller; it comes to 3 minutes 55.91 seconds a day, and this is meant when we say that "the stars gain about four minutes daily."

NOTE: We could use any star as a test star but Beta of Cassiopeia has the advantage of being practically on the zero hour circle, and you can read the sidereal time from this hour circle as though from a clock hand, any night of the year; if you have the sidereal time you can, by simple addition of four minutes a day, figure out your own solar time. It's a nice pastime and could even be useful. How to do it is shown on the next two pages.