The Tilt of the Earth's Axis and the Consequences Thereof

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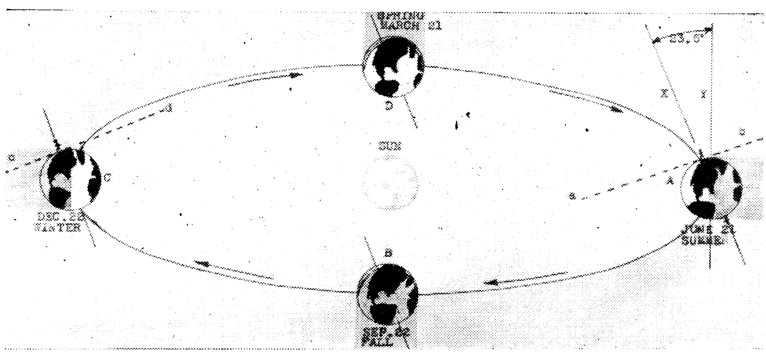
The earth goes around and sun once each year, and the plane of its motion is called the plane of the ecliptic. The earth rotates once each day; and the axis of its rotation lacks 23.5 degrees of being perpendicular to the plane of the ecliptic. This angle of 23.5 degrees is called the inclination of the earth's axis, and is one of the most important facts concerning the earth's motion, since it causes the seasons. If the axis of the earth were perpendicular to the plane of the ecliptic the climate at any given point on the earth would remain the same the year around.



The sun, as we see it, has two apparent motions: (a) it rises in the east, crosses the sky, and sets in the west; this apparent motion is, of course, caused by the rotation of the earth; (b) the path of the sun as it crosses the sky, is continually shifting back and forth across the equator over a belt that has a width of twice 23.5 degrees or 47 degrees. Half of the year the sun appears to be north of the equator, and half, south of the equator. This apparent shift of the path of the sun is due to the inclination of the earth's axis.

This paper with its diagram, charts, and graphs is designed to make clear the effects of the inclination of the earth's axis. As a teacher of astronomy I am often called upon to explain the when, where, and why of sunrises and sunsets. The answer to these questions may be obtained with little trouble by any one who knows the facts which are illustrated in this paper. These facts are of great value to aviators, architects, home builders, and world travelers. One who knows the full meaning of the inclination of the earth's axis will not be puzzled by the movements of the sun as seen from poles, the equator, or any other point on the earth. There is just about as much satisfaction in knowing the positions of the sun from day to day, as there is in keeping up with the calendar. At some time in high school every student should be taught the simple facts concerning the relations of the earth and sun.

The Diagram

In the preceding pages the apparent motions of the sun were defined. These apparent motions are, of course, due to the real motions of the earth. It is the purpose of the diagram, and the discussions which are to follow, to explain how the real motions produce the apparent motions. In this

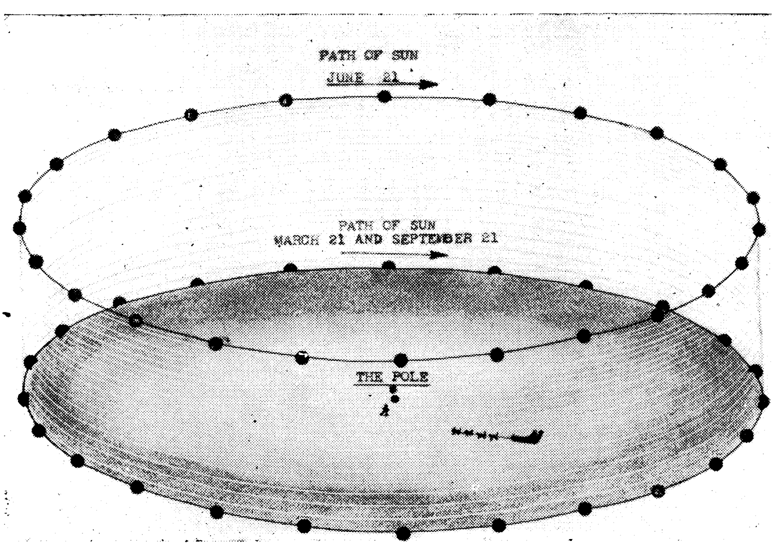


Chart I. Latitude 90° N. This shows how the sun would appear to move if seen from the North Pole.

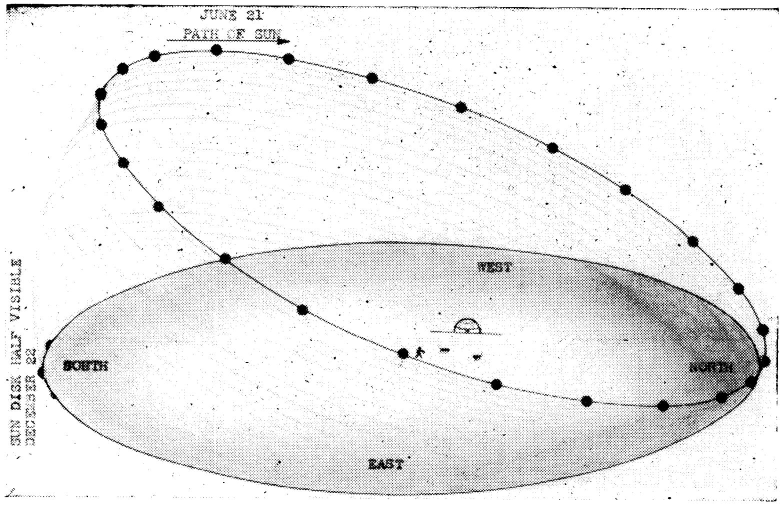


Chart II. This shows how the sun would appear to move to a man living at 66.5° North Latitude. [The following cities are on or near 66.5° N.L.: Fairbanks, Alaska (64°), North Magnetic Pole (66°), Murmansk, U.S.S.R. (68°), Archangel, U.S.S.R. (64°).]

conventional diagram the earth is represented in four different positions along the path which it follows around the sun. In the study of the diagram the reader should not forget: (a) the revolution of the earth; (b) the rotation of the earth; (c) the fixed direction of the earth's axis of rotation.

When the earth is in position *A* (June 21) the tilt of the axis is exactly towards the sun, and this causes the sun to appear to be 23.5 degrees higher than it would be if the axis had no tilt; and "the little man" at the north pole sees the sun at an altitude of 23.5 degrees above the horizon. Since this little fellow is turning with the earth, the sun to him, appears to be running around and around the sky at a fixed altitude of 23.5 degrees. If he were in any other position in the northern hemisphere, the sun, because of the tilt, would appear to be elevated at midday by this amount. This elevation of the sun causes the northern hemisphere to receive the maximum amount of heat, and to have its summer season.

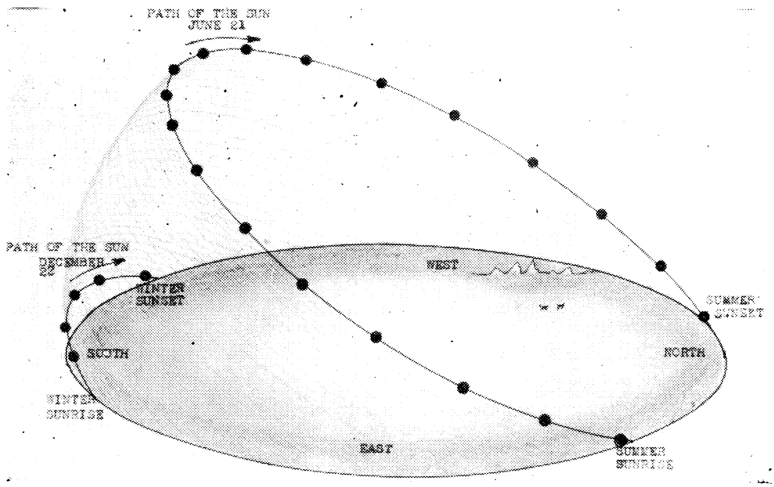


Chart III. This shows how the sun would appear to move at 60° North Latitude. [The following are on or near this parallel to latitude: Juneau, Alaska (68°), Hudson's Bay (60°), Leningrad (60°), Oslo (60°), Helsinki (60°), Stockholm (60°), Moscow (56°).]

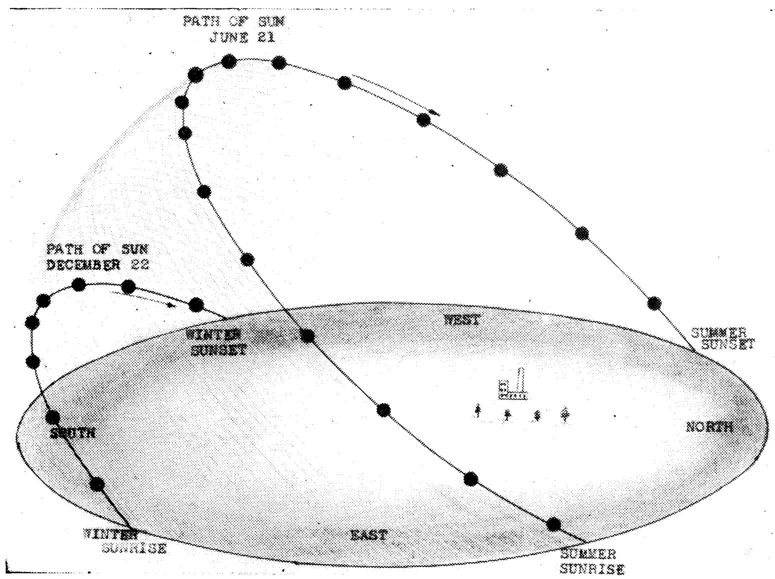


Chart IV. This shows how the sun would appear to move, at 50° North Latitude. [The following cities and places are on or near this parallel: Vancouver, B. C. (50°), Newfoundland (48°), London (53°), Paris (49°), Berlin (53°), Warsaw (53°), Kiev, U.S.S.R. (50°), Kharkov, U.S.S.R. (50°), Stalingrad (48°).] Maximum length of day, 16 hr., 22 mins., minimum length, 8 hr., 4 mins.

As the earth moves on around toward position *B*, the direction of the sun from the earth gradually departs from the direction of the tilt and when it reaches position B, the two directions are at right angles to each other. This means that the tilt has no effect upon the altitudes of the sun; hence the two hemispheres receive equal amounts of heat; it is eqinox. As the earth moves toward position *C*, the direction of the sun and the direction of the tilt depart more and more, and finally become opposite when the earth reaches position *C*. At this time the altitude of the sun is lowered by 23.6 degrees and it is midwinter. As the earth moves on past position *C*. the changes described above take place in the reverse order, and return to the initial conditions when the earth gets back to *A*. The cycle of changes, as seen from the southern hemisphere, are the same as those of the northern hemisphere, except that they come six months later. In the changes of the relative directions

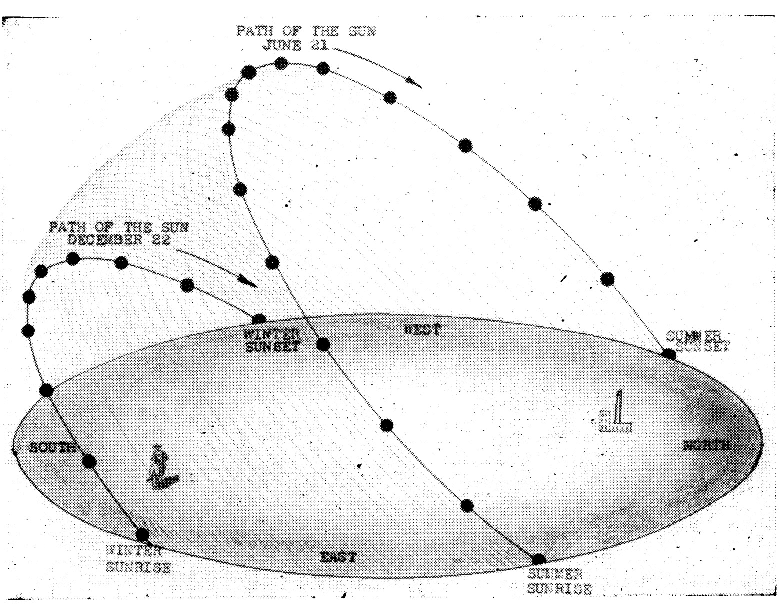


Chart V. This shows how the sun would appear to move if seen from 40° North Latitude. [The following places are on or near this parallel: Denver (40°), Philadelphia (40°), New York City (41°), Madrid (41°), Naples (42°), Peiping (40°), Tientsin (40°), Ankara, Turkey (40°), Baku, U.S.S.R. (41°).]

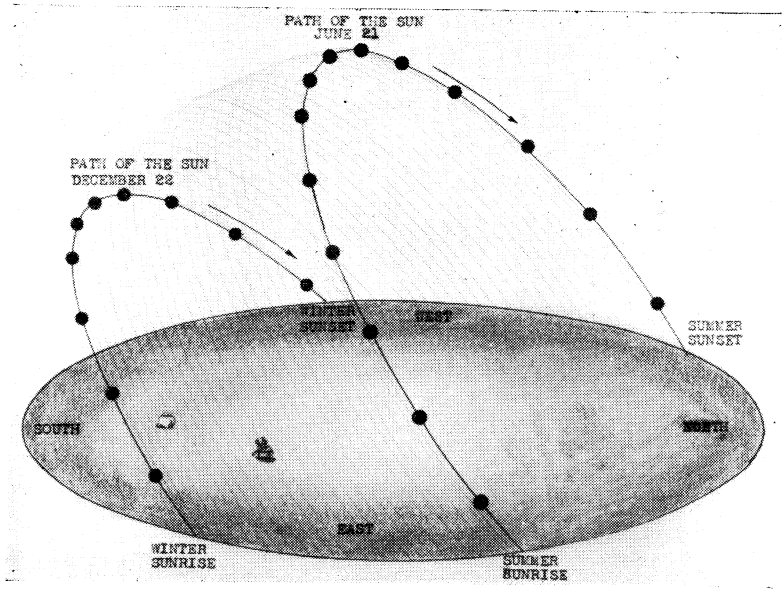


Chart VI. This shows how the sun would appear to move if seen from 30° North Latitude. [The following cities are on or near this parallel: Austin, Texas (29°), New Orleans (30°), Jacksonville, Fla. (30°), Cairo, Egypt (30°), Chungking, China (29°).]

of the sun and the tilt of the earth's axis, we find the explanation of the apparent shift of the sun back and forth across the equator over a belt that has a width of 47 degrees.

Problems

Suppose an architect who is planning a home for a citizen of Dallas, wishes to know the maximum angle at which the sunlight will fall on a south window in midsummer and midwinter. The equation used is as follows:

$$A = 90° — (L — D)$$

A is the altitude; *L* is the latitude of Dallas; and *D* is the distance of the sun north or south of the equator. If the sun is south of the equator, *D* takes the negative sign.

Solution for midsummer, June 21):

Latitude of Dallas 32.6 degrees; Distance sun is north of equator 23.5 degrees—

$$A = 90° — (32.6° — 23.5°) = 80.9 \text{ degrees.}$$

Solution for midwinter, (Dec. 22):

$A=90°-(L-(-D))=90°-(32.6°-(-23.5°))=34.7$ degrees.

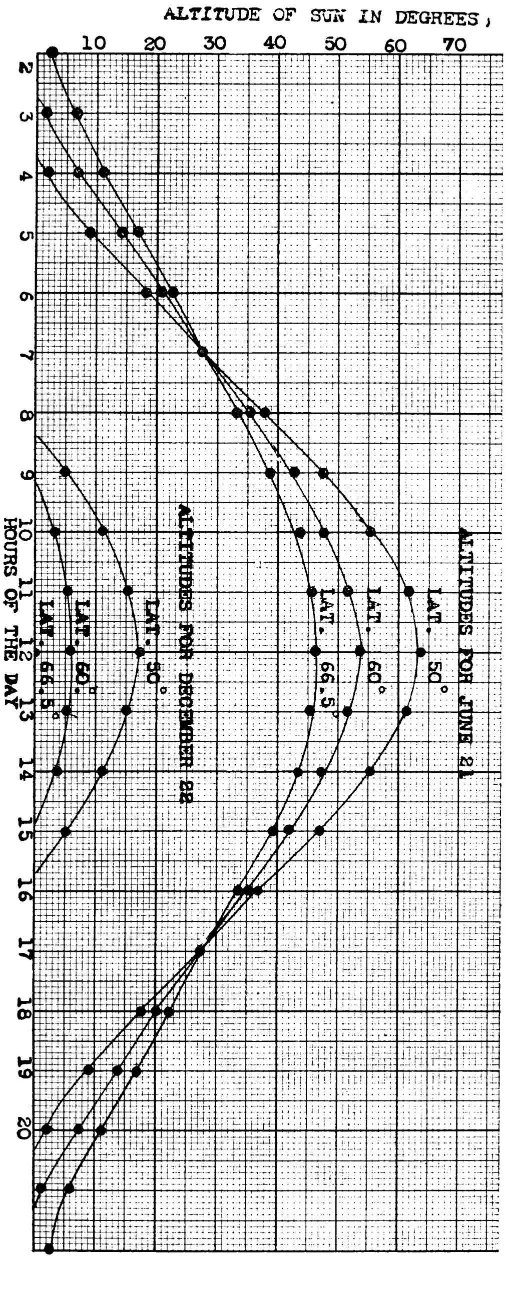
The value of D may be obtained from the *American Ephemeris and Nautical Almanac,* or by estimation from chart I. If the chart is used, remember that the spiral rings which represent the path of the sun are nearer together at the top, and the bottom of the 47 degree belt than they are at the center. D in the *Almanac* is called declination.

The Charts

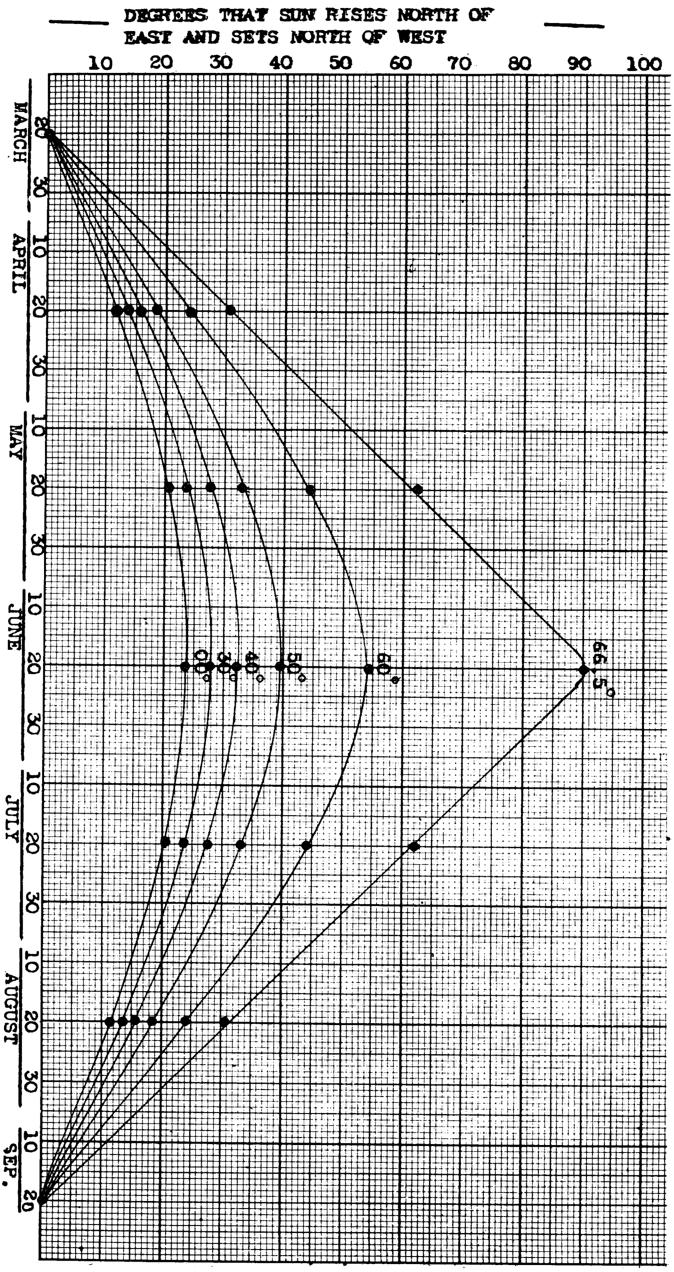
The charts are designed to show the path of the sun as seen from different latitudes and different dates. In all cases the shaded ellipse represents the horizon of the observer, and the unshaded ellipse, the path of the sun as seen from the northern hemisphere on June 21. The large black dots represent the hourly positions of the sun, and the dim spirals the path of the sun as it shifts back and forth across the equator.

In Chart I the sun, as seen by the man at the North Pole on March 21, is skimming the horizon half-visible and half-invisible. As the days go by, it climbs the dim-line spiral like a giant firefly climbing a giant corkscrew and reaches the rim of the upper ellipse on June 21. After June 21 it descends the spiral and is once more on the horizon on September 21. After this date it spirals below the horizon and is out of sight for six months. If the man at the North Pole could jump to the South Pole on September 21, he would see the motions just described taking place in the reverse direction with the sun reaching its maximum altitude on December 22. The time required for the sun to spiral upward from the horizon to the rim of the upper ellipse is about 91 days, hence there should 91 turns in the spiral between the equator and the upper extreme, a number much to large to be shown on the drawings.

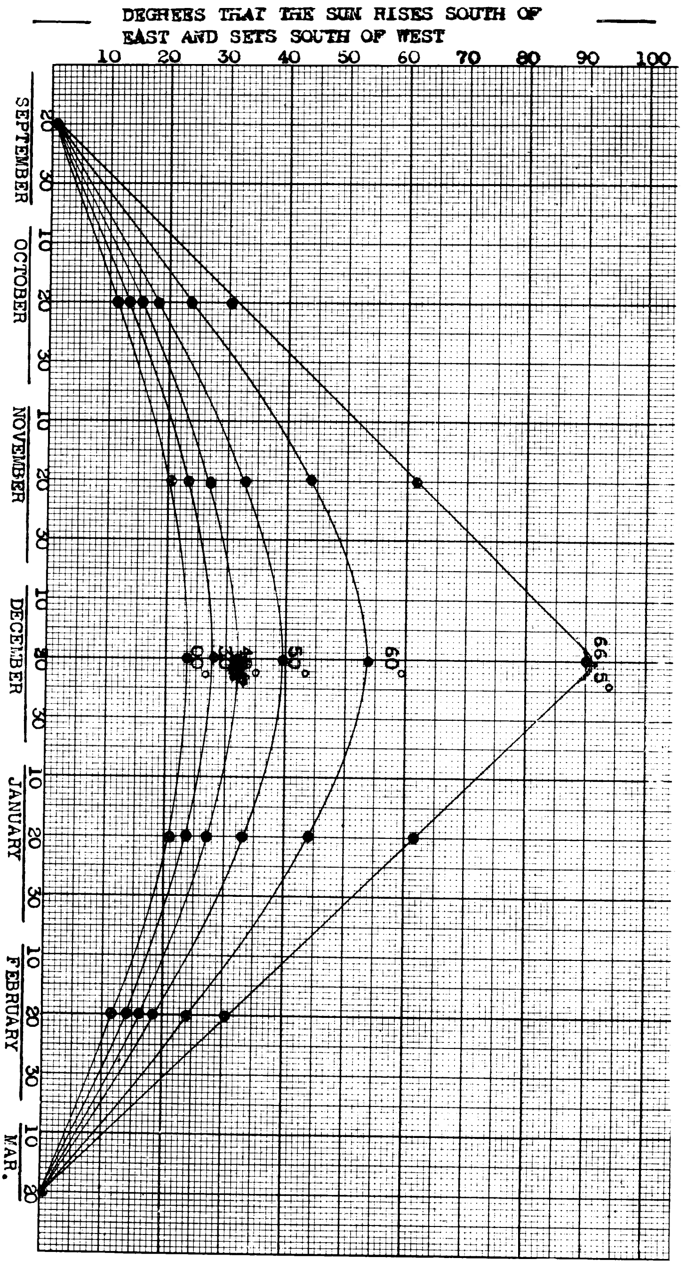
All drawings are for the northern hemisphere. They may be made applicable to the southern hemisphere by changing places with June 21 and December 22, changing places with the words "North" and "South," and reversing the direction of the arrows. Logical reasoning will make clear the meaning of the other charts.



Sun Altitude Graph for Latitudes 66.5°, 60.0°, 50°.



Graphs showing where the Sun rises and sets, at Latitudes 66.5°, 60.0°, 50.0°, 40.0°, 30.0°, 00.0°.



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