AN INTRODUCTION TO ASTRONOMY

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Astronomy

by

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An Introduction to Astronomy

PREFACE TO THE FOURTH EDITION

In this new edition the book is considerably rewritten. A chapter on telescopes is added, and the introduction to the spectroscope here permits the chapter on the sun to be moved to a more suitable place. Descriptions of the star fields in the later chapters are rearranged to provide a separate chapter on the circumstellar and interstellar material. Suggestions for supplementary reading and reference are brought together at the end of the book.

The general plan of the book remains the same as in the previous editions. It undertakes to present an elementary account of astronomy which can serve as a text without special prerequisites.

The author's thanks are due to Dr. Bart J. Bok and Dr. Priscilla F. Bok for their critical reading of the manuscript.

ROBERT H. BAKER

University of Illinois Observatory,
January, 1952.

PREFACE TO THE FIRST EDITION

The methods which have proved useful in the larger text, "Astronomy," are employed again in this simpler "Introduction to Astronomy." This textbook is designed for shorter introductory courses. It undertakes to tell the story of the heavens in a way that will be understandable without special preparation.

Beginning right at home, with familiar aspects of the earth and sky, the descriptions progress by easy stages through the solar system to the stars, and finally to the galaxies beyond our own. Lists of questions at the ends of the chapters give opportunities for review, and brief lists of references suggest further reading on the various subjects.

The maps and the descriptions of the constellations, in Chapter V, are intended to promote the familiarity with the prominent star figures which adds much to the interest in the beginning course in astronomy. Many celestial photographs throughout the book, which have been generously contributed for the purpose, supplement the written accounts of features beyond the reach of the unaided eye.

The author is indebted to Professor Schlesinger for his critical reading of the entire manuscript, and to Dr. Harry E. Crull who read the manuscript and cooperated in the preparation of the lists of questions.

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CHAPTER 1

THE EARTH AND THE SKY

THE GLOBULAR EARTH — THE CONVENTIONAL GLOBE OF THE SKY — SOME EFFECTS OF THE EARTH'S ATMOSPHERE

A small planet attending the sun which is but one of the multitudes of stars, the earth owes its importance to the fact that we live here. Here we view the celestial scene around us. In order to interpret the scene aright we first consider the earth that looms large in the foreground. The science of the stars begins at home. Our study of astronomy begins with the globe of the earth at the center of the apparent globe of the heavens, and encompassed by the atmosphere through which we look out at the celestial bodies.

The Globular Earth

Primitive people supposed that the earth was flat, except for its mountains and valleys. Those who lived in fairly level country frequently pictured the earth as a circular disk; they were at its center, while around its rim the sky shut down like an inverted blue bowl. It is easy to imagine a world like this as we look around us, and it is often convenient to represent the sky as an inverted bowl.

1·1. The Earth's Curved Surface. The idea that the earth is a globe was taught by learned men as early as the 5th century B.C. It was prompted at first by the fitness of things; the earth ought to be a globe to match the globe of the heavens which they now imagined as completely surrounding the earth. Presently the Greek scholars were calling attention to evidence that the earth is globular, or at least that its surface is curved.

The progressive disappearance of a ship as it puts out to sea shows that the earth curves downward from the place of observation; the superstructure of the ship remains visible for a time after the hull has gone down out of sight.

A similar effect on land is shown in the photograph of the Andes Mountains (Fig. 1·1), which was taken from an airplane 4 miles aloft over the plains of Argentina nearly 300 miles east of the mountains. Above the line where the sky and a floor of haze seem to meet, the more

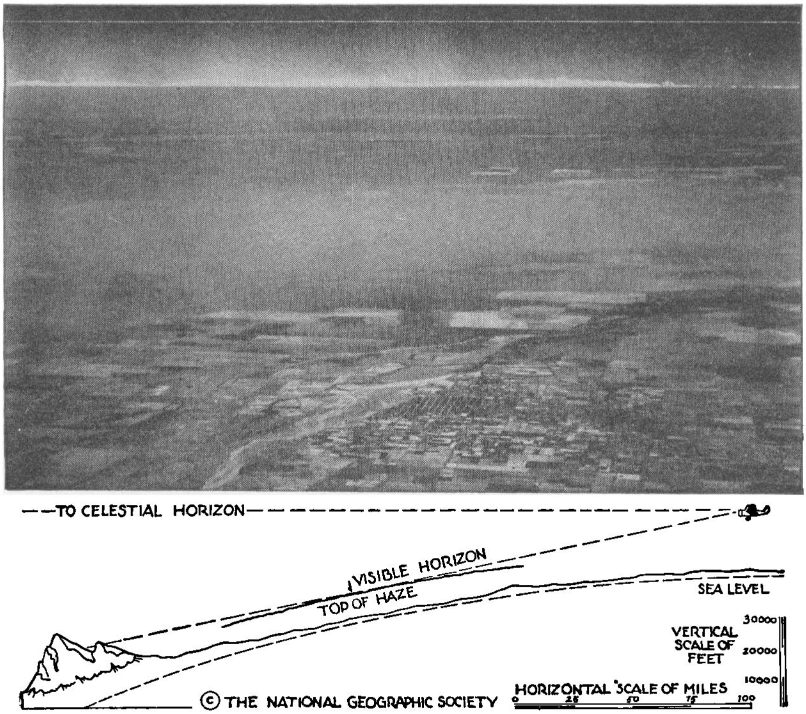

FIG. 1·1. The Earth's Surface Is Curved. Photograph from an airplane 4 miles above sea level in Argentina. The white line at the top represents the celestial horizon. The visible horizon 153 miles away is formed by the top of a stratum of haze 6700 feet high. Above this horizon the tops of the Andes rise nearly 300 miles from the airplane. (*Courtesy of The National Geographic Society*)

distant peaks of the Andes rise like the superstructure of a departing ship. This sky line itself appears slightly curved, a feature which becomes pronounced in photographs from rockets at much higher elevations (Fig. 1·1A).

The earth's shadow on the moon during a partial eclipse is always part of a dark circle, a shadow that a globe would cast. Such evidence of the earth's rotundity was mentioned by Aristotle in the 4th century B.C. Another effect that he cited is familiar to almost everyone.

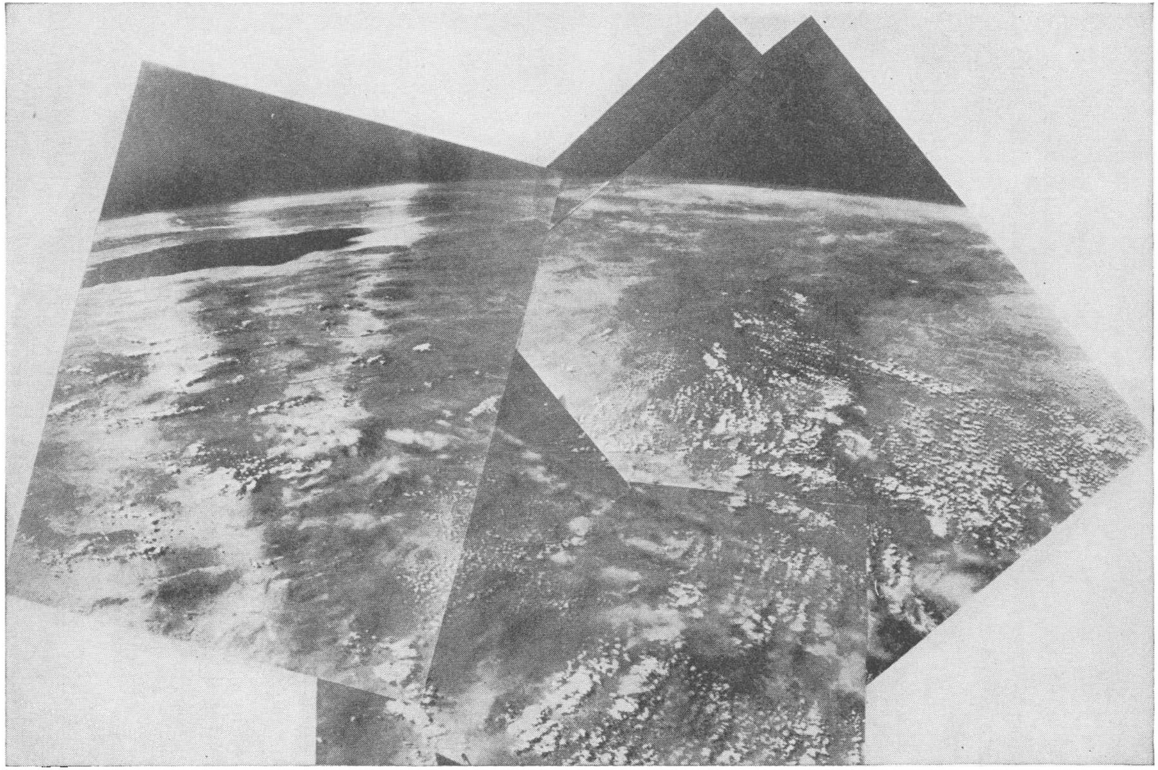

FIG. 1·1A. The Earth Viewed from the Altitude of 101 Miles. A mosaic of 4 photographs from a V-2 rocket launched from the Army Ordnance Proving Ground at White Sands, New Mexico. The picture covers about 500,000 square miles of southwestern United States and northern Mexico. (*Courtesy of Naval Research Laboratory, Washington*)

1·2. The Stars Shift as We Travel. When we travel north or south, the daily courses of the celestial bodies across the sky are displaced in the opposite direction by an amount that is nearly proportional to the distance traveled. Stars pass overhead that did not do so before. If we travel south from middle northern latitudes, constellations such as the Southern Cross, which could not be seen at home, make their appearance above the southern horizon. This evidence of the earth's

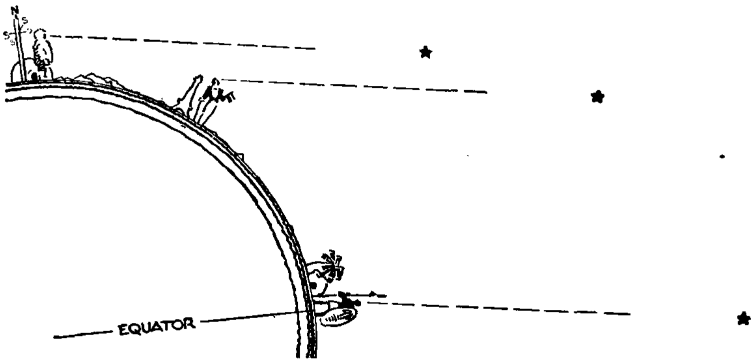

FIG. 1·2. The Courses of the Stars Shift in Proportion to the Distance We Travel North or South.

curvature was observed by the early Greeks when they traveled south to Egypt.

The idea that the earth is a globe was accordingly not a new one when Columbus began his voyages; but the dimensions of the globe were not agreed on at that time. Columbus' plan to reach India by a shorter route toward the west arose from his acceptance of an estimate of the size of the earth that was much too small.

1·3. Measuring the Earth. If the earth were perfectly spherical, all meridians—north and south lines around it—would be great circles equal in size to the equator. The earth's circumference could be determined in this event simply by measuring the length of 1° of a meridian and multiplying by 360, the number of degrees in the circumference of a circle. The length of 1° of a meridian is the number of miles we must travel north or south (2·11) to shift the daily courses of the celestial bodies 1° in the opposite direction.

Measurements of the size of the earth were made in about this way almost as early as the recognition of the earth's globular form. The best known and perhaps the most accurate of the early attempts was made in the 3rd century B.C. by Eratosthenes, geographer and librarian of the museum in Alexandria. He observed that the sun at noon at the beginning of summer stood a fiftieth of the circumference of the heavens away from the point directly overhead. At Syene (near Assuan), some

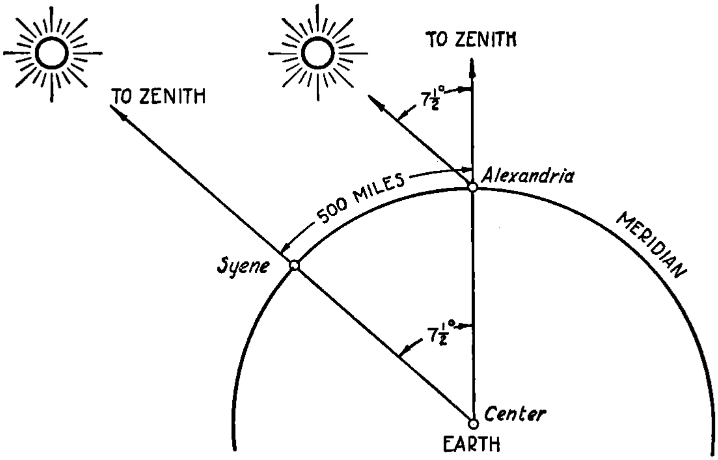

FIG. 1·3. Eratosthenes' Measurement of the Earth's Circumference. The sun passed 7½° from the zenith of Alexandria when it was directly overhead at Syene 500 miles to the south. The circumference is accordingly 360°/7½° times 500, or 25,000 miles. (For the purposes of illustration, the scales and the angles shown have been greatly exaggerated.)

500 miles south of Alexandria, the sun was said to be directly overhead at noon on that day. The earth's circumference would accordingly (Fig. 1·3) be 25,000 miles.

1·4. The Earth Bulges at the Equator. If the earth were a perfect sphere, except for its mountains and depressions, a degree of latitude would have the same length everywhere. Accurate measurements in various parts of the world show that this is nearly true. One degree of latitude equals:

68.7 miles near the equator,
68.8 miles near latitude 20°,
69.0 miles near latitude 40°,
69.2 miles near latitude 60°,
69.4 miles near the poles.

The progressive increase in the values with increasing distance from the equator means that the meridians curve most rapidly near the equator and least rapidly near the poles. The earth is accordingly (Fig. 1·4) an oblate spheroid; it is flattened at the poles and bulged at the equator.

The earth's diameter at the equator is 26.7 miles greater than the diameter from pole to pole. The difference is slight compared with the size of the earth. If the earth is represented by an 18-inch globe, the diameter of this globe is only a sixteenth of an inch greater at the equator than at the poles. A globe such as this could easily pass casual inspection as a perfect sphere.

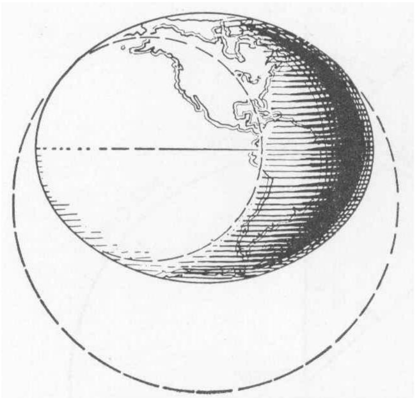

FIG. 1·4. A Meridian Is Part of a Larger Circle at the Pole than at the Equator. The difference between the equatorial and polar diameters is greatly exaggerated.

1·5. The Constitution of the Earth. The earth's equatorial diameter is 7926.68 miles, and its polar diameter is 7899.98 miles. These are the dimensions of the spheroid that most nearly fits the irregular surface of the earth. The unit is the statute mile, equal to 5280 feet.

The earth's mass is 6.6×10^{21} tons, or 66 followed by twenty ciphers. The material averages $5\frac{1}{2}$ times as dense as water; it becomes denser with increasing depth. Near the surface the temperature of the rocks rises about 1° F for each 50 feet of descent. Even if the increase is more gradual farther down, the temperature in the deep interior may be high enough to melt the rocks in ordinary conditions. However, the melting points of the rocks are higher there because of the greater pressure.

The "crust" of the earth contains much granite frequently topped with sedimentary rock and underlain with basalt. At greater depths there are heavier layers composed largely of silicates of iron and magnesium. The still heavier core of the earth, some 3000 miles in diameter, is dense enough to be composed of nickel-iron alloys, like most of the large meteorites. An alternate idea is that the core differs from the less dense layers above it only because the material has collapsed under the very great pressure.

1·6. The Earth Viewed from Outside. The photographs at the beginning of the chapter, which show a part of the earth as viewed from the altitude of 101 miles, give an idea of how the earth would appear

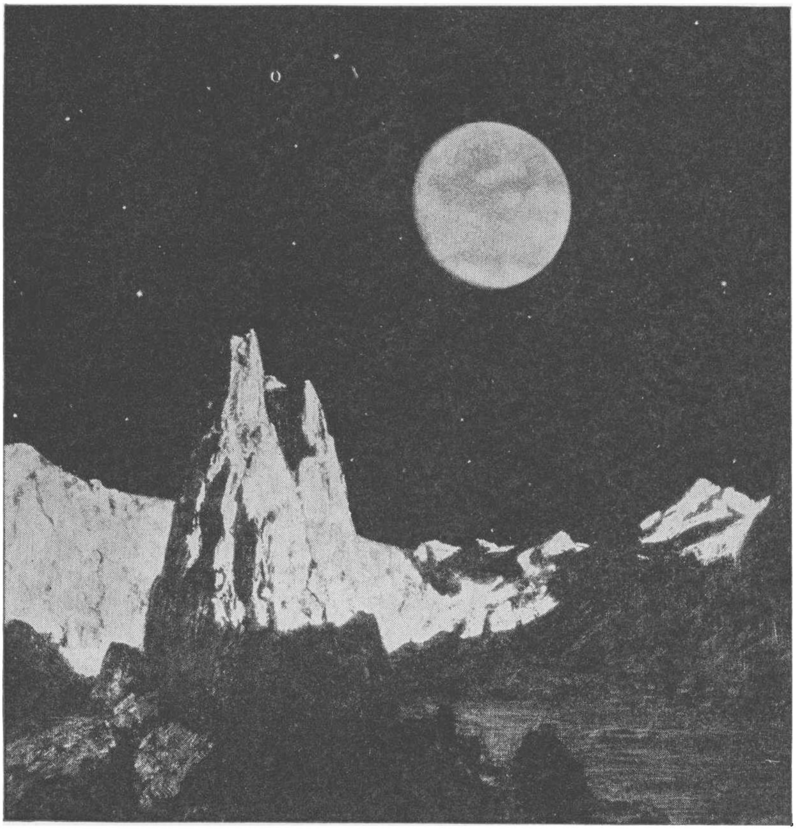

FIG. 1·6. The Earth as Seen from a Crater on the Moon. From a painting by Howard Russell Butler. (*Courtesy of the American Museum of Natural History, New York*)

from the moon through a telescope magnifying 2400 times. It would appear as a great globe having its surface more or less obscured by drifting clouds. As indicated by the Gulf of California at the upper left in Fig. 1·1A, bodies of water would contrast clearly with the land areas.

Observed with the unaided eye from the moon, the earth would appear among the constellations in the lunar sky (Fig. 1·6) nearly 4 times as great in diameter as the moon does in our skies and would become some 60 times as bright at its full phase. Large dark areas on its disk might be incorrectly interpreted by the watcher on the moon, because oceans seem to be a geographical feature unique to the earth. Large bright areas formed by clouds and snowfields would add variety to the scene. The works of man would be difficult to detect.

From the nearest planets the earth would appear as a bright star, moving along through the constellations of the zodiac as it revolves around the sun. From the outermost planets the earth would be lost in the glare of the sun, which itself would be reduced to the appearance of a brilliant star.

1·7. Positions on the Earth. One way of denoting positions on the earth's surface is with reference to natural or conventional areas. It is often satisfactory to an inquirer if we say, for example, that Havana is in Cuba or that Cleveland is in Ohio. A second way, especially when positions are required more accurately, is with reference to circles, or nearly circles, that we imagine on the earth and represent on globes and maps. These familiar circles are mentioned here so that we may notice presently their resemblance to circles imagined in the sky.

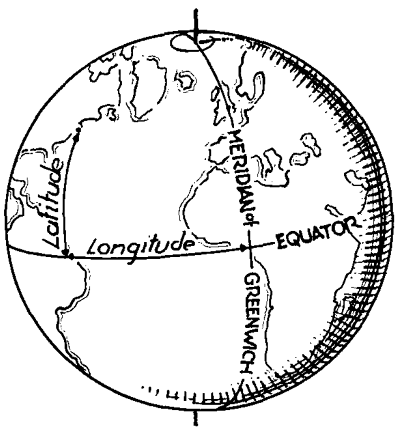

FIG. 1·7. Longitude and Latitude.

The earth's *equator* is the great circle halfway between its north and south poles. *Meridians* pass through both poles and, accordingly, at right angles to the equator; they are slightly elliptical, but are considered as circles for most purposes of navigation. The *prime meridian,* or *meridian of Greenwich,* passes through the original site of the Royal Observatory at Greenwich, England. It crosses the equator in the Gulf of Guinea at the point where the longitude and latitude are zero.

The *longitude* of a place is its angular distance east or west from the prime meridian. Longitude is expressed in degrees, from 0° to 180° either way, or else in hours (2·10). The *latitude* of a place is its angular distance in degrees north or south from the equator, from 0° to 90° either way. As an example, the longitude of Yerkes Observatory at

Williams Bay, Wisconsin, is 88° 33′ W, or $5^h\,54^m\,13^s$ W, and the latitude is 42° 34′ N.

THE CONVENTIONAL GLOBE OF THE SKY

1·8. The Celestial Sphere. Although the stars are scattered through space at various distances from the earth, the difference in their distances is not perceptible to ordinary observation. All the stars seem equally remote. As we view the evening sky, it is easy to imagine that the celestial bodies are set like jewels on the inner surface of a vast spherical shell.

Regarded in early times as the tangible boundary of the visible universe, the *celestial sphere* survives only as a convenient way of representing the heavens for many purposes. By this convention the stars can be shown on the surface of a globe or in projection on a plane map. Their positions can then be denoted in very much the same way that positions are defined on the globe of the earth.

The center of the celestial sphere can be the center of the earth, the observer's place on the earth's surface, the sun, or anywhere else we choose. The size of the sphere is as great as we care to imagine it. Parallel lines, regardless of their distance apart, are directed toward the same point of the sphere, just as the parallel rails of a track seem to converge in the distance.

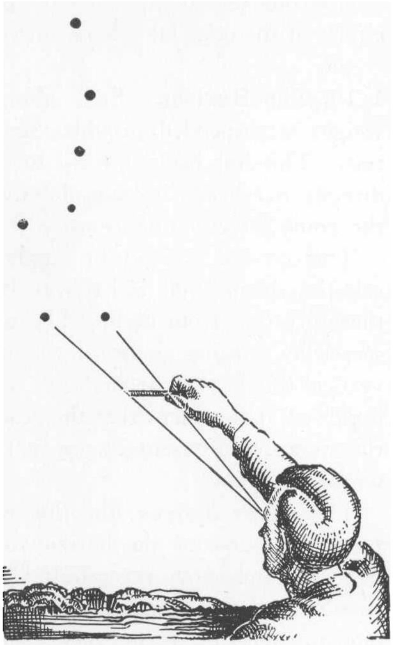

FIG. 1·9. The Distance Between the Dipper's Pointers Is About 5°.

1·9. Places of the Stars. The apparent place of a star is its place on the celestial sphere. It signifies the star's direction and nothing else about its position in space. If two stars have nearly the same direction from the earth, although one may be more remote than the other, they have nearly the same apparent place. We speak similarly of the apparent places of the sun, moon, and planets. We say that the sun is entering the constellation Leo and remark on the nearness of the moon to a bright star.

The *apparent distance* between two celestial bodies is accordingly their difference in direction; it is often called the *distance* between them, when there is no chance for ambiguity. Such distances are expressed in degrees or other angular measure. The apparent distance between the Pointers of the Great Dipper is somewhat more than 5°. This is often used as a measuring stick for estimating other distances in the sky.

How shall we describe the place of a star so that others will know where to look for it? One way is to specify the constellation in which the star appears. If we say that the star Algol is in the constellation Perseus, anyone who can recognize the different constellations then knows about where this star is situated. It is much like saying that New Haven is in Connecticut.

A second way of denoting the place of a star is with reference to the circles of the celestial sphere, such as the horizon.

1·10. The Horizon. Sight along a vertical line. A cord to which a weight is suspended provides such a line when the weight comes to rest. This line leads upward to the *zenith,* the point in the sky that is directly overhead; it leads downward through the earth to the *nadir,* the point directly underfoot.

The celestial horizon, or simply the *horizon,* is the great circle of the celestial sphere that is halfway between the zenith and nadir, and is therefore 90° from each. The direction of the horizon is readily observed by sighting along a level surface, perhaps a table top. Since the vertical line is at right angles to the earth's surface and since this surface is curved, it is evident that the positions of the zenith and horizon among the stars are different at any particular time in different parts of the world.

The *visible horizon,* the line where sky and earth seem to meet, is rarely the same as the horizon of astronomy. On land it is usually irregular and above the celestial horizon. At sea it is a circle in calm weather and lies below the celestial horizon; this *dip* of the sea horizon increases with increasing height of the observer's eye above the level of the sea.

1·11. The Celestial Meridian. *Vertical circles* are great circles of the celestial sphere which pass through the zenith and nadir and accordingly cross the horizon vertically. Most important of these circles is the