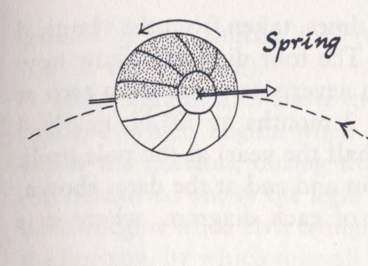


1 Sky

1.1 The Land of the Midnight Sun

"The Arctic" means different things to different people. To those who pay more attention to the sky than to the ground (which includes astronomers, of course), it means all that part of the earth, centered on the North Pole, where, at least once in the year, the sun remains above the horizon for a full 24 hours without setting so that (if it isn't cloudy) the sun shines at midnight on at least one day of the year.

An understanding of why there are days in summer when the sun doesn't set (and days in winter when it doesn't rise) cannot be gained without concentrating closely on astronomical matters, specifically on the way the earth rotates around a tilted axis as it makes its yearly journey round the sun. Readers not in the mood for heavy thinking on these topics should skip to section 1.3.

The lowest latitude at which the midnight sun is ever seen is the Arctic Circle, at 66½° N (or at 23½° from the Pole; the two angles add up to a right angle). The reason for this can be understood from the diagram (fig. 1.1) showing how the axis on which the earth spins (joining the north and south poles) is tilted at an angle of 66½° to the earth's orbit round the sun. The day of the year on which the tilted axis points most nearly toward the sun is known as the summer solstice; it comes on June 21. On that day, as the diagram shows, every point within the Arctic Circle is in sunlight for the whole of the earth's rotation, that is, the whole day long. At the other end of the year is the winter solstice (December 22) when, at every point within the Arctic Circle, the sun is below the horizon the whole day long.

Contemplation of figure 1.1 shows that the times of sunrise and sunset must change with the seasons. The exact times, taken from the Nautical Almanac, were used to draw figure 1.2. The four diagrams show how the number of days during which the sun never sets varies from zero at 60° N (below the Arctic Circle) to over 2 months at 70° N, nearly 4 months at 80° N, and finally 6 months (half the year) at the pole itself. These periods of continuous sunlight begin and end at the dates shown, respectively, on the left and right sides of each diagram, where it is

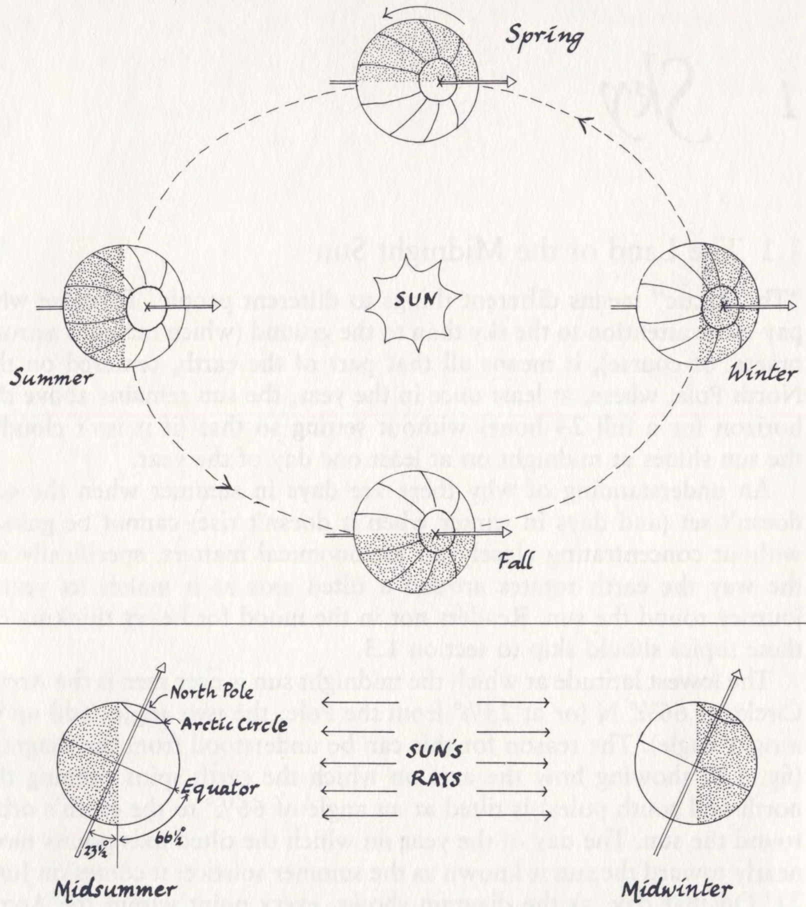


Figure 1.1. *Above:* The earth in its orbit round the sun, seen from above. The direction the earth spins is shown at the top. The arrow through each globe is the earth's axis, with the arrowhead pointing north. The axis is tilted, with the arrowhead raised up from the page through an angle of 66½°. The circle around the pole (marked X) is the arctic circle. Shaded: dark side of the earth, not in sunlight. *Below:* Side views of the earth at midsummer (left) and midwinter (right).

crossed by the "sunrise line" (the line separating the white part from the rest of the diagram).

The diagrams also show the duration of two kinds of twilight: *Civil twilight,* which begins when the sun sets and continues until it is 6° below the horizon; during this period "operations requiring daylight" can be carried on, as the legal description puts it. And *nautical twilight,* which begins when civil twilight ends and lasts until the sun is 12° below the horizon, by which time all the stars used for celestial navigation have "come out." In the morning, of course, the order is reversed: first comes nautical twilight and then civil twilight, which ends at sunrise.

There is a third level of twilight, so dim it is treated as darkness in the diagrams. It prevails while the sun is between 12° and 18° below the horizon, and is called *astronomical twilight.* During astronomical twilight, fainter stars appear, and the outlines of large objects and the horizon remain just visible. When the sun is lower than 18°, darkness is total (except for moonlight, starlight, the aurora, and nightglow, the faint radiance of the night sky itself!).

The diagrams can be used to give (roughly) the times of sunrise and sunset, and of the beginnings and ends of the two kinds of twilight, on a chosen date at each of the latitudes shown. For example, a horizontal line through April 1 on the 70° N diagram, shows that on that day, at that latitude, nautical twilight begins at about 2 A.M. and ends at about 10 P.M. Civil twilight begins at about 4 A.M. and ends at about 8 P.M. Sunrise and sunset are at 5 A.M. and 7 P.M., respectively. On the same day at 80° N, civil twilight lasts all night, even though the sun is below the northern horizon for the 3½ hours centered on midnight. And at the pole, the sun doesn't set at all on that day.

The dates at which (at a particular latitude) the sun sets for the long winter night and rises at the end of it, can also be read, approximately, from the relevant diagram. They are the dates shown on the right and left sides of the diagram (respectively) where it is cut by a horizontal line across it, drawn so as to touch the bottom of the dip in the "sunrise line." At 70° N, for example, the sun disappears at the end of November and reappears in the middle of January. The corresponding dates at 80° N are late October and late February. The special conditions at 90° N—the Pole itself—are described later.

Note that, when the long winter night comes to an end, the sun first shows itself on the *southern* horizon. The first "day" lasts from a few seconds before noon to a few seconds after, when the sun is in the south. Astronomical considerations clearly show that the first sunrise of the year is never in the east even though writers accustomed to temperate latitudes sometimes forget this.

To return to the midnight sun: Even when the sun doesn't set, there is a noticeable difference in temperature between midday (when the sun is due south) and midnight (when it is due north) in all but the highest latitudes. The words "day" and "night" are often used, despite the continuous daylight, to label the warmer and cooler halves of the 24-hour day. The temperature difference is because at midday the sun is at the highest point in its path through the sky, and at midnight at its lowest point. The contrast is most marked on the Arctic Circle, where, on its

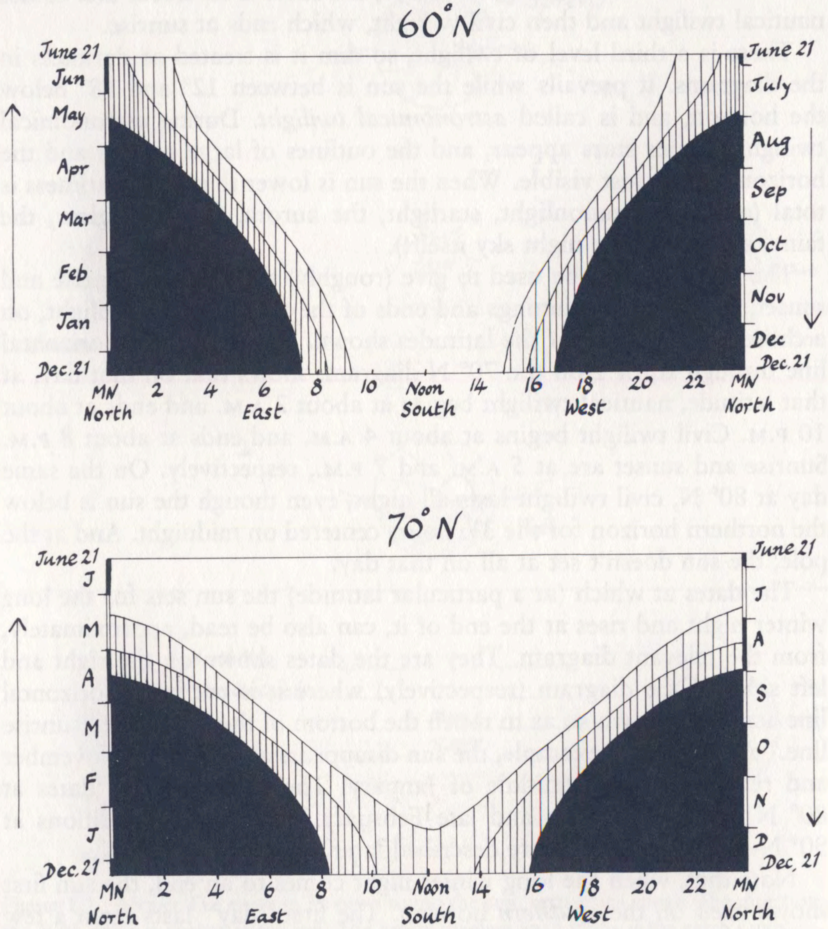
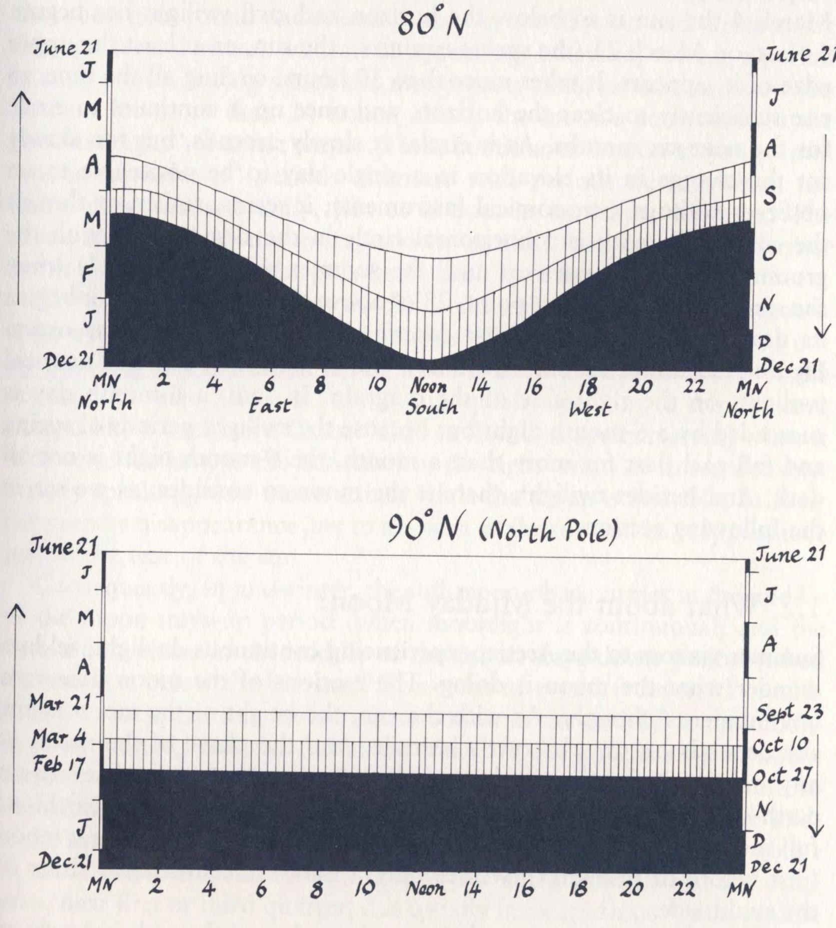


Figure 1.2. The times of twilight, sunrise and sunset at four latitudes, 60° N, 70° N, 80° N, and 90° N (the North Pole). The 24 hours from midnight (MN) to midnight are shown along the bottom in each diagram; the labels North, East, South and West show the direction of the sun at different times through the day (from the North Pole, all directions are South). Dates are shown on the left and right sides, following the arrows:

single annual appearance (June 21), the midnight sun is right on the horizon. The contrast between day and night becomes less and less as the midnight sun period becomes longer and longer, that is, the farther north you go: as the latitude increases, the height of the sun above the horizon at midday becomes progressively less, and its height at midnight becomes progressively greater, until at the North Pole itself they become equal.

The course of events right at the pole deserves special attention (see



from midwinter (December 21) upward through spring to midsummer (June 21) on the left; from midsummer downward through fall to midwinter on the right. For any date, *read all the way across the diagram* for the course of events on that day. Full darkness is shown black; nautical twilight by close rulings, civil twilight by wide rulings. (More details in the text.)

fig. 1.2). After months of winter darkness (relieved only by the moon; see sec. 1.2), a day comes when a faint glow becomes just noticeable at some point on the horizon. The glow does a complete rotation, along the horizon, every 24 hours as day succeeds day (measuring days on a clock). By February 17, many of the fainter stars have become invisible in the brightening sky and the horizon can just be seen; the sun is 12° below the horizon and nautical twilight has begun. The light continues to increase gradually, as the sun slowly rises; it does not show itself, but its position below the horizon is obvious from the glow in the sky. By March 4 the sun is 6° below the horizon and civil twilight has begun. At last, on March 21 (the spring equinox), the sun, or at least the upper edge of it, appears. It takes more than 30 hours, circling all the time, to rise sufficiently to clear the horizon, and once up it continues to circle for the next six months. As it circles it slowly ascends, but too slowly for the change in its elevation in a single day to be noticeable to an observer without astronomical instruments; it seems, rather, as though the sun's daily path is a horizontal circle in the sky, parallel with the ground. The ascent goes on until the summer solstice (June 21) when the sun reaches its highest point, 23½° above the horizon. Then it begins its descent and the events just described all happen in reverse order. Figure 1.2d shows the dates of sunset, and of the end of civil and nautical twilight, on the right side of the diagram. In sum, a 6-month day is succeeded by a 6-month night but because the twilight periods of spring and fall each last for more than a month, the 6-month night is not all dark. And besides twilight, there is the moon to consider, as we see in the following section.

1.2 What about the Midday Moon?

Summer visitors to the Arctic, experiencing continuous daylight, seldom wonder what the moon is doing. The motions of the moon deserve a few moments' thought. As with the sun, the height of the moon in the sky depends on the observer's latitude. And the phase of the moon at any moment—the shape of its sunlit side as seen by an observer on earth—depends on the relative positions of sun, moon, and earth. At full moon, we see the whole of the moon's sunlit side; near new moon (just before or just after), we see only a thin, crescent-shaped sliver of the sunlit side.

The moon revolves around the earth, and goes through its cycle of phases from new moon through first quarter (a half-moon shaped like a D) to full moon, and on through third quarter (a backward D) to the next new moon, in the course of one lunar month (about 29 days). Its

orbit around the earth is almost (within about 5°) in the same plane as that of the earth's orbit around the sun. As a result, there are what could be called "moon seasons" of the same pattern as the familiar "sun seasons"; but the full cycle of moon seasons takes only a month instead of a whole year.

At latitudes greater than 72° N (i.e., 5° or more north of the Arctic Circle) there is a period in each month during which the moon never sets, remaining above the horizon for more than 24 hours; this is the moon's equivalent of the sun's midnight-sun period. During this period the moon goes round and round in the sky for days on end, progressing through several phases without disappearing. Likewise, there is a period in each month during which the moon never rises, remaining below the horizon for more than 24 hours; this is the moon's equivalent of the "endless night" of arctic winter. These continuous "moon-stays-up" and "moon-stays-down" periods alternate with periods during which the moon rises and sets daily, just as it does in temperate latitudes. The moon-stays-up and moon-stays-down periods last longer the farther north you go until, at the pole itself, each lasts for half a month.

The next question is: how do the moon's phases change in the moon-stays-up and moon-stays-down periods? The answer can be figured out by recalling that the moon is full when it is on the opposite side of the sky from the sun. And it is "new," colloquially speaking (a thin crescent shaped like a backward C), or "old" (a thin C-shaped crescent) when it is close to the sun, to the left (east) or the right (west) of it, respectively. Strictly speaking, new moon comes while the moon is invisible, halfway between its disappearance just to the west of the sun and its reappearance just to the east of the sun.

Consequently, in midwinter, the full-moon phase comes in the middle of the moon-stays-up period (when moonlight is continuous); and the new moon phase in the middle of the moon-stays-down period (when the moon is below the horizon). The order of events is reversed in midsummer; then, the new moon phase comes in the middle of the moon-stays-up period, and the full-moon phase in the middle of the moon-stays-down period. The result is that the moon is seldom visible to midsummer travelers in the Arctic. For much of the time that the midnight sun is shining, the moon is either below the horizon, or, if above it, too close to the sun to be visible in the sun's glare. When it can be seen, near first or third quarter, it is usually inconspicuous—pale against a pale sky.

In figures 1.3 and 1.4 are sky maps showing the moon's paths through the sky, in a midwinter month and a midsummer month, as seen from latitude 73° N. Viewing each map from the left edge across to the right

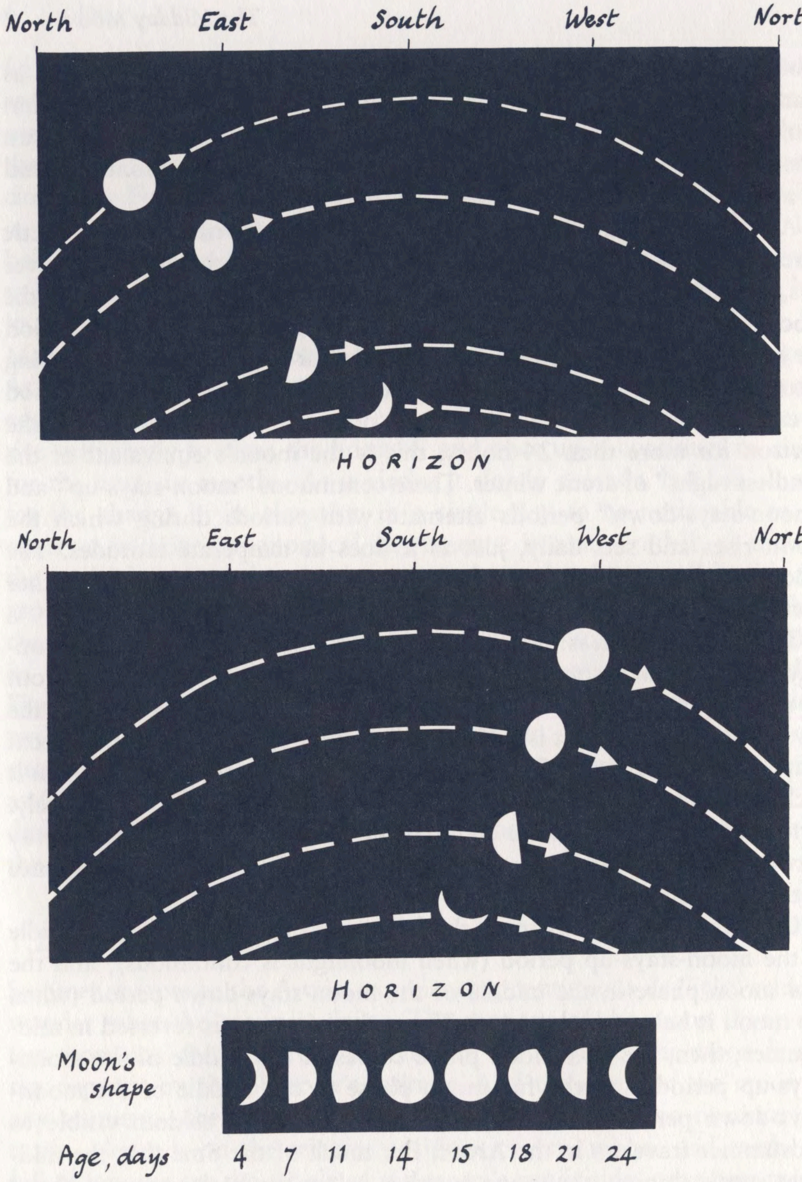


Figure 1.3. The two maps together show the path of the moon in its apparent daily circuits round the sky, during a midwinter month (when the sun never rises), as seen from 73° N latitude. For clarity, only 8 of these circuits are shown. The lower edge of each map is the horizon. In periods when the moon never sets its path cuts the left and right edges of the map instead of the horizon. The dashed lines in the upper map show (from right to left ascending) the moon's path and shape when it is 4, 7, 11 and 14 days old, respectively. The dashed lines in the lower map show (from right to left descending) the moon's path and shape when it is 15, 18, 21 and 24 days old, respectively. The outlines at the bottom show the moon's shape as it ages from a 4-day old moon to a 24-day old moon, i.e., through all that part of the month when it is above the horizon.

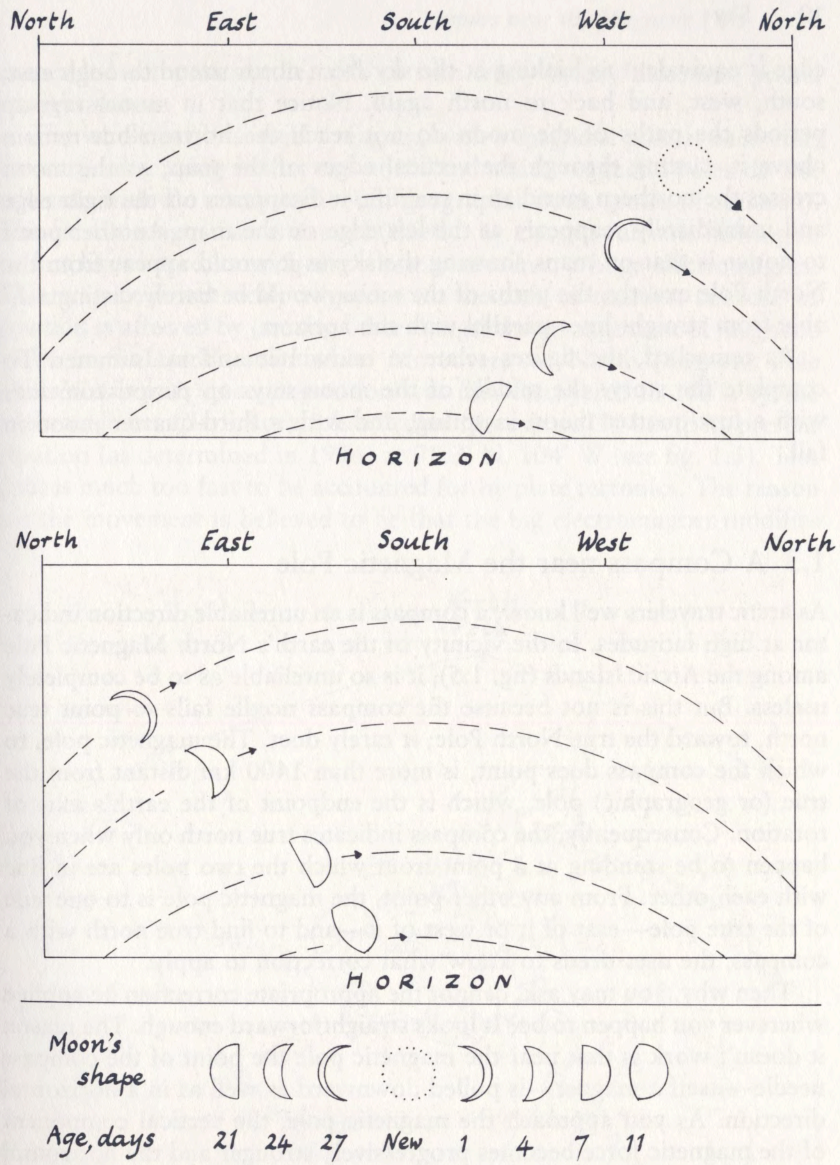


Figure 1.4. As fig. 1.3, but for a midsummer month, when the sun never sets. The dashed lines in the upper map show (from left to right ascending) the moon's path and shape when it is 21, 24, and 27 days old and at New Moon, respectively. (At New Moon the moon is too near the sun to be visible anywhere on earth; in the diagram it is shown as a dotted outline.) The dashed lines in the lower map show (from left to right descending) the moon's path and shape when it is 1, 4, 7 and 11 days old, respectively, in the lunar month starting with New Moon in the upper map. The outlines at the bottom show the moon's shape as it ages from a 21-day old moon to an 11-day old moon in the following lunar month, i.e. through all that part of the month when it is above the horizon. Note that when it is a thin crescent, the moon is so close to the sun (which doesn't set) as to be invisible in its glare.

edge is equivalent to looking at the sky from north round through east, south, west, and back to north again. Notice that in moon-stays-up periods the paths of the moon do not reach the horizon but remain above it, cutting through the vertical edges of the map; as the moon crosses the northern meridian in real life, it disappears off the right edge and immediately reappears at the left edge on the map. Another point to notice is that on maps showing the sky as it would appear from the North Pole exactly, the paths of the moon would be barely distinguishable from straight lines parallel with the horizon.

As remarked, the figures relate to midwinter and midsummer. To complete the story: the middle of the moon-stays-up period coincides with a first-quarter moon in spring, and with a third-quarter moon in fall.

1.3 A Compass near the Magnetic Pole

As arctic travelers well know, a compass is an unreliable direction indicator at high latitudes. In the vicinity of the earth's North Magnetic Pole among the Arctic Islands (fig. 1.5), it is so unreliable as to be completely useless. But this is not because the compass needle fails to point true north, toward the true North Pole; it rarely does. The magnetic pole, to which the compass does point, is more than 1400 km distant from the true (or geographic) pole, which is the endpoint of the earth's axis of rotation. Consequently, the compass indicates true north only when you happen to be standing at a point from which the two poles are in line with each other. From any other point, the magnetic pole is to one side of the true pole—east of it or west of it—and to find true north with a compass, the user needs to know what correction to apply.

Then why, you may ask, cannot the appropriate correction be applied wherever you happen to be? It looks straightforward enough. The reason it doesn't work is that near the magnetic pole the point of the compass needle—itself a magnet—is pulled downward as well as in a horizontal direction. As you approach the magnetic pole, the vertical component of the magnetic force becomes progressively stronger and the horizontal component progressively weaker until the latter is too weak to overcome the friction in the bearings of even the most expensive compass. The needle moves sluggishly and where it stops is merely a matter of chance. At the magnetic pole itself, the magnetic pull is wholly downward and there is no horizontal component. This is how its location is recognized: it is the site at which the *magnetic dip* (the angle that the magnetic force makes to the horizontal) is 90°: in other words, where a suitably

suspended compass needle, able to turn freely in any direction, points straight down.

The whole earth is itself a magnet, with a magnetic pole at each end; the surprising thing is that the north and south magnetic poles do not coincide with the north and south geographic poles (poles of rotation). The earth's magnetism is caused (chiefly) by electric currents flowing in its hot liquid core, turning the whole planet into a huge electromagnet. This magnet is not tidily aligned with the axis of rotation because its position is affected by (among other things) the arrangement of magnetic rocks in the earth's solid crust. Moreover, the North Magnetic Pole doesn't stay put: since its position was first discovered in 1831, by the explorer James Clark Ross, it has drifted more than 750 km to its present position (as determined in 1994) at 78.3° N, 104° W (see fig. 1.5). This drift is much too fast to be accounted for by plate tectonics. The reason for the movement is believed to be that the big electromagnet modifies

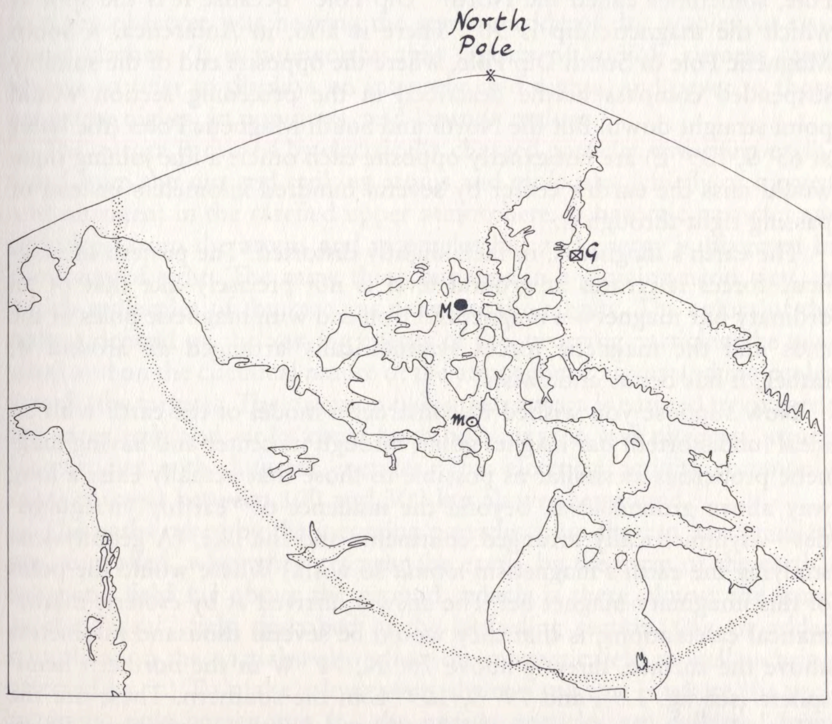


Figure 1.5. Showing the location of: *m*, the North Magnetic Pole in 1831. *M*, the North Magnetic Pole at present (1990s). *G*, the North Geomagnetic Pole (see sec. 1.4). The stippled band is the Auroral Oval (see sec. 1.5).

the electric currents in the core, which then modify the electromagnet itself, which then modifies the currents again, which then . . . , and so on. The explanatory theories devised by physicists involve electromagnetism, hydrodynamics, viscosity, electrical and thermal conductivity, and much else.

Besides "drifting," the magnetic pole also "wobbles": every day it travels round a closed path, roughly elliptical in shape and often more than 100 km across. This it does in response to the electomagnetic effect of electrical currents in the upper atmosphere, caused by electrified particles pouring in from the sun.

1.4 The Geomagnetic Pole

Some maps of the north polar regions show a North Geomagnetic Pole as well as a North Magnetic Pole. This needs explanation. First note that the pole described in the preceding section is the North Magnetic Pole, sometimes called the North "Dip Pole" because it is the spot at which the magnetic dip is 90°. There is also, in Antarctica, a South Magnetic Pole or South Dip Pole, where the opposite end of the suitably suspended compass needle described in the preceding section would point straight down. But the North and South Magnetic Poles (the latter at 65° S, 139° E) are not exactly opposite each other: a line joining them would miss the earth's center by several hundred kilometers instead of passing right through it.

The earth's magnet is, in fact, slightly distorted. The pattern of magnetic forces it creates at ground level is not precisely like that of an ordinary bar magnet—a magnetized iron rod with magnetic poles at the ends and the magnetic forces symmetrically arranged all around it; rather, it has bends and twists.

Now suppose you wished to construct a model of the earth with an ideal (undistorted) bar magnet going through its center and having magnetic properties as similar as possible to those that actually exist a long way above ground level, beyond the influence of "earthly" irregularities—asymmetrically arranged continents and the like. (A geophysicist studying the earth's magnetism *would* so wish.) Where would the poles of this imaginary magnet be? The answer, arrived at by esoteric mathematical calculations, is that they would be several thousand kilometers above the surface, directly above 79° N, 71° W in the northern hemisphere (see fig. 1.5), and 79° S, 109° E in the southern. These are the points shown on a map as the North and South Geomagnetic Poles, respectively; unlike the "dip" poles, they are at opposite ends of a line going through the earth's center.

There is nothing to observe when you arrive at, or rather under, the North Geomagnetic Pole; it is about as theoretical as anything can be. It drifts, though slowly, moving approximately northwest at about 2 km per year. And its position is related to the aurora.

1.5 The Aurora Borealis, or "Northern Lights"

When the arctic sky is totally dark—which it never is, of course, in high summer—the chances are favorable for seeing a display of the aurora borealis, or northern lights. In good displays, the glowing, shimmering, flickering lights sometimes take the form of arcs or bands, sometimes of rippling draperies, and sometimes of rapidly pulsating patches of light streaming upward through the sky. The color is usually pale green, very occasionally red or violet.

Contrary to legend, the aurora makes no sound: it is silent. Reports of shushing sounds probably mean that the observer was hearing the swish of dry snow blown over hard snow crust, and of crackling sounds that the observer was hearing the static crackle of dry woolen or synthetic clothes. (It is noteworthy that reports of audible auroras seem always to refer to displays on intensely cold nights, and never to those on warm nights, in populous, mid-latitude regions.)

The aurora is caused by electrically charged particles streaming earthward from the sun and striking atoms and molecules (chiefly of oxygen and nitrogen) in the rarefied upper atmosphere. Subatomic particles are dislodged from the atoms and molecules hit, and energy is liberated in the form of light. The same thing happens in a glowing neon sign, in which molecules of the rare gas neon are the targets. The colors of the aurora depend on the varying energy of the incoming particles (the missiles) and on the chemical nature of the atmospheric atoms and molecules struck (the targets). The common pale green aurora is emitted by oxygen; the rarer reds and violet come from both oxygen and nitrogen, struck by particles with different energies. This electrical activity commonly takes place at between 100 and 300 km above the ground.

The paths taken by the incoming particles from the sun (the missiles) are controlled, when they get near the earth, by the form of the earth's magnetic field far above the ground, which is there almost the same as the "ideal" field described in the preceding section. (As an added complication the particles also affect the magnetic field as well as being affected by it.) To make a long story short—and this is where the geomagnetic pole comes into it—the missile particles are deflected from their original straight line paths in a way that makes most of them converge toward a more or less oval ring, centered on the geomagnetic (not the magnetic) pole. This oval is called the *auroral oval* (see fig. 1.5). It marks the zone where auroras are most often seen and are at their most splendid; they become progressively less frequent and less splendid as you go away from the oval, either inward or outward. Near the center of the oval, directly below the geomagnetic pole, auroras are no more common than they are over, for example, Montreal or Duluth. Outside the oval, auroras become less and less frequent until they almost peter out altogether. In a nutshell, look for the most spectacular auroras in North America along the southern border of the Low Arctic tundra, a suitably inspiring setting.