THE ROTATION OF THE SUN

The sun turns once every 27 days, but some parts turn faster than others. Such variations are clues to interrelated phenomena from the dense core outward to the solar wind that envelops the earth

by Robert Howard

When Galileo turned his telescope on the sun in 1610, he discovered that there were dark spots on the solar disk. Observing the motion of the spots across the disk, he deduced that the sun rotated once in about 27 days. One of his contemporaries, Christoph Scheiner, undertook a systematic program of observing the spots. From these observations Scheiner found that the rotation period of the spots at higher solar latitudes was slightly longer than that of the spots at lower latitudes. In the middle of the 19th century R. C. Carrington, a wealthy English brewer and amateur astronomer, determined with good precision the amount of the variation of the sun's rotation rate with latitude.

Scheiner's observations suggested that the sun does not rotate as a simple solid body. Since we now know that the sun is a gas throughout, it does not surprise us that it does not rotate as a solid. One might have expected, however, that the spots closer to the sun's equator would move slower than the spots at the higher latitudes, just as the outer planets of the solar system move slower in their orbits than the inner ones. The fact that the equatorial regions rotate faster than the rest of the sun implies that an excess of angular momentum—the momentum of the sun's rotation—must be transferred from the higher solar latitudes to the equatorial regions. This fact and its implications yield information about the structure of the sun's interior and the nature of its activity.

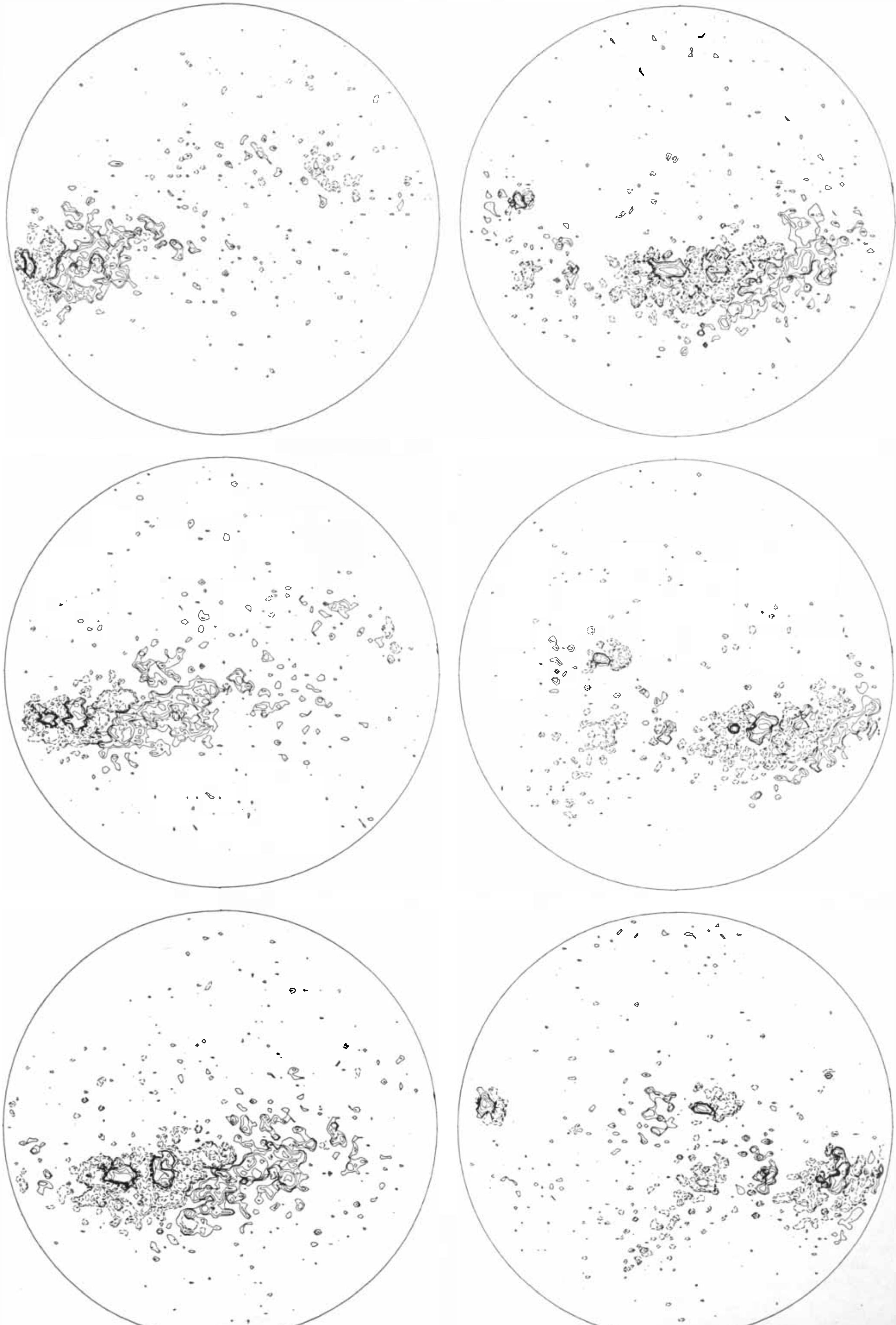
There are two basic methods for precisely determining the rotation of the sun at a particular latitude. The first is to time the passage of some tracer (such as a sunspot) across the solar disk. The second is to photograph the spectrum of the sun; the spectral lines of the solar atmosphere will be Doppler-shifted because the gas that gives rise to them is moving, and the amount of the shift is proportional to the velocity of the gas in the line of sight. Unfortunately for solar observers each method has disadvantages that limit its usefulness.

Timing a tracer as it crosses the disk of the sun is a good technique for determining the solar rotation rate only if the tracer meets certain requirements. First, it must survive long enough unchanged in its appearance to be useful over some reasonable period of time. Second, it must have a clearly defined structure, so that its position can be accurately determined. Third, it must be at the same altitude in the sun's atmosphere when it is seen at the center of the solar disk and when it is seen at the edge. Last, it must not wander around the solar disk in some systematic way not directly related to the sun's rotation.

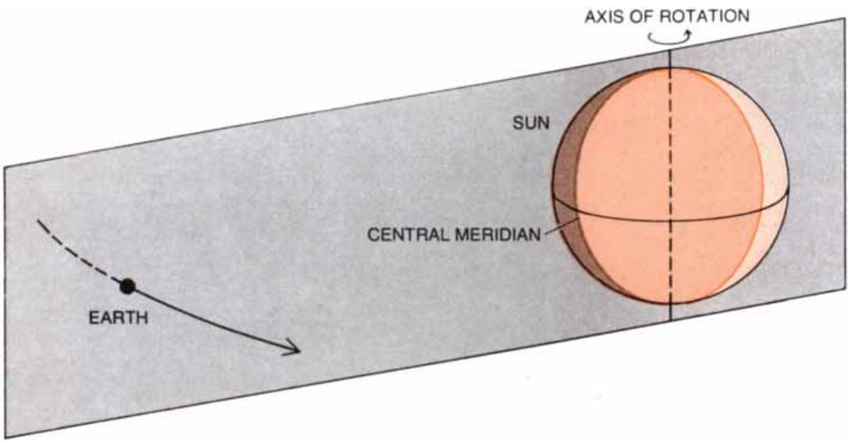
Although no features on the sun meet all these requirements, sunspots are still the easiest to observe, and they have been studied more than any other tracer. Thus they have probably provided the most accurate determinations of the sun's rotation. When sunspots are observed with a small telescope, they appear simply as spots on the photosphere: the bright surface of the sun that is seen in ordinary white-light photographs. In larger telescopes they may appear as saucer-shaped depressions near the edge of the sun. Therefore it is hard to be sure that the same point in the sunspot is being used for the purpose of measurement as the spot traverses the solar disk and is seen from a different angle each day. In order to avoid the problem, students of the sun's rotation prefer to use long-lived spots that cross the central meridian of the sun more than once. The central meridian is defined as the intersection of the sun's visible surface with the plane that passes through the sun's axis of rotation and the earth; when a sunspot crosses the central meridian, the effect of its three-dimensional form is minimized and its position can be most precisely measured.

Only a small fraction of sunspots live long enough to cross the central meridian more than once. The spots with the longest lifetime are the ones found on the leading edge of groups of sunspots,

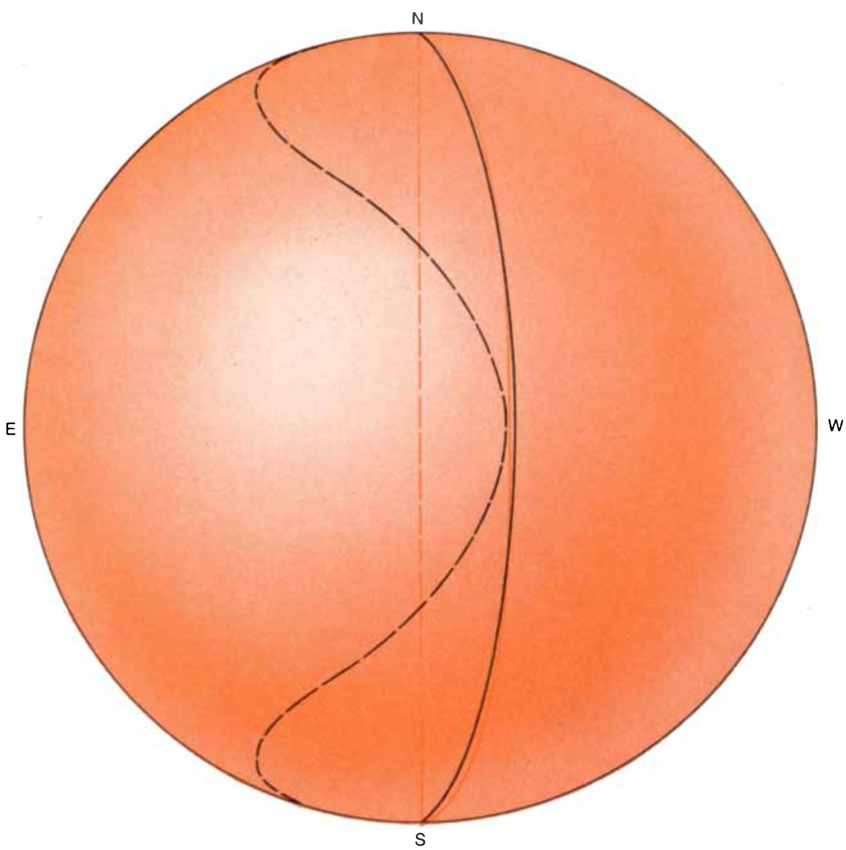
SUN'S ROTATION can be monitored by noting the daily progress across the solar disk of a tracer such as a sunspot or a gaseous filament. Such features are associated with magnetic fields, which can be detected directly by means of a solar magnetograph. The six magnetograms on the opposite page were made with the 150-foot tower telescope at the Mount Wilson Observatory. The sequence reads from top to bottom and shows the magnetic activity on the sun at intervals of every other day from May 30, 1974, through June 9, 1974. The contours on the magnetograms represent equal-strength areas in the magnetic fields. The strength in gauss of the fields at successive contour intervals is five, 10, 20, 40 and 80. (The strength of the earth's magnetic field is less than one gauss.) The solid contours represent positive magnetic fields; the broken contours represent negative fields. The lifetimes of the smallest magnetic features are less than a day, so that in general it is possible to trace the daily rotational movement of only the larger magnetic features. Strongest of active regions that are seen here are associated with sunspots; it is difficult to determine the exact location of spots, however, because angular resolution of magnetograms is low. Evolutionary changes within active regions somewhat alter their appearance from day to day.



and so these are the ones that are most commonly monitored. That is actually unfortunate, because the preceding and following members of a sunspot group tend to separate early in the lifetime of the group. In addition the preceding spots tend to exhibit systematic motions of their own later in their lifetime. A further disadvantage of using sunspots as rotation tracers is that they are rarely seen above a solar latitude of 35 degrees. Thus they can be used only for determining the rotation of the sun at rather low latitudes.



CENTRAL MERIDIAN OF THE SUN as it is seen from the earth is defined as the intersection of the portion of the sun visible from the earth (*color*) with the plane (*gray*) defined by the sun's axis of rotation and the earth. Longitudinal positions of the various markers that are monitored to study sun's rotation are referred to sun's central meridian.

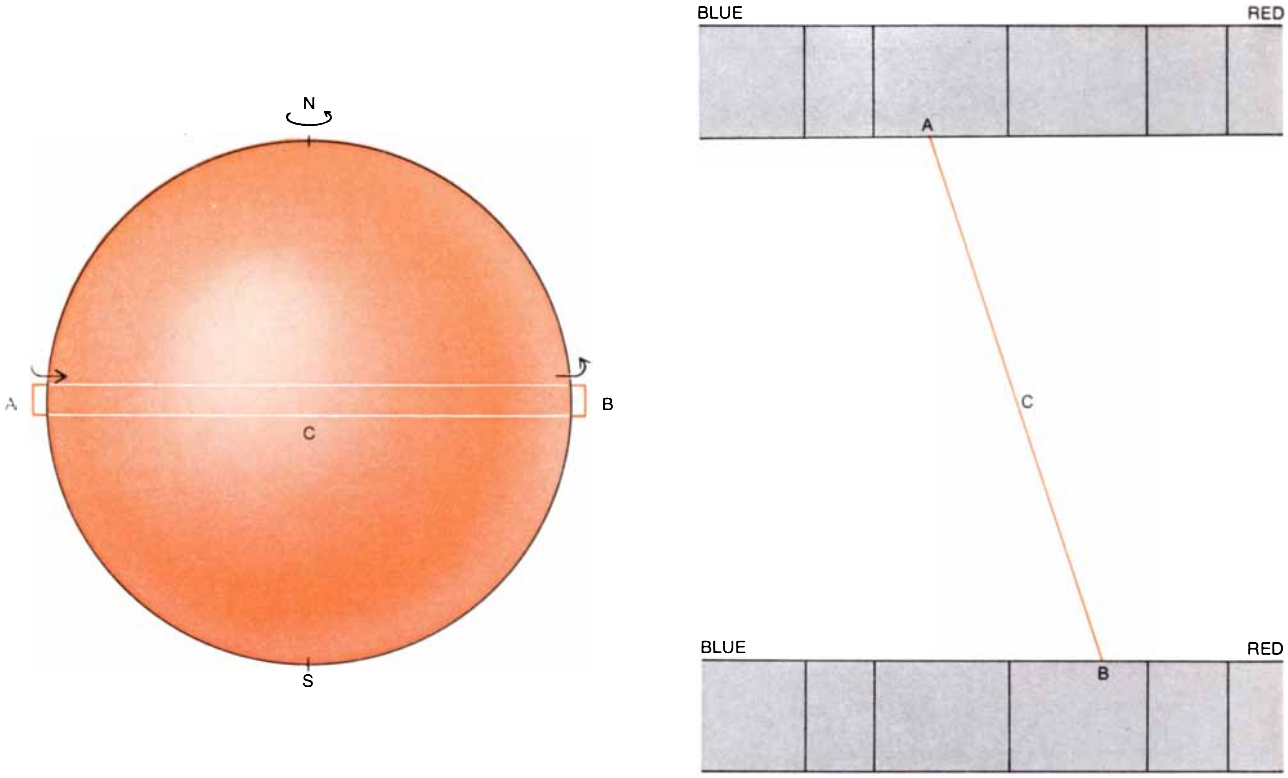


SUN DOES NOT ROTATE AS A SOLID BODY but rotates differentially with latitude. The lines in color indicate position of tracers after one day (*solid line*) and 27 days (*broken line*) if the sun rotated as a solid body. The lines in black indicate their actual positions after one day (*solid line*) and 27 days (*broken line*) and illustrate the effects of the sun's differential rotation. In general the higher the latitude, the longer the rotation period.

A second kind of tracer is the long filaments of gas in or above the solar chromosphere. The chromosphere is the transitional layer between the photosphere, which has a temperature of 6,000 degrees Kelvin, and the solar corona, which paradoxically is much hotter: about two million degrees K. The chromosphere can be observed only at the wavelengths of certain spectral lines, notably the line designated hydrogen alpha in the red region of the spectrum. Photographs of the chromosphere made in the light of the hydrogen-alpha line show an abundance of lovely detail. Although most of these features are too short-lived or too ill-defined to be used for accurately determining the rotation rate of the chromosphere at various latitudes, large dark filaments are fairly reliable tracers. The filaments are actually clouds above the chromosphere that appear dark when they are seen projected against its bright surface but appear bright when they are seen extending beyond the edge of the solar disk. They are not ideal tracers because their appearance changes too rapidly. Their lifetime is not negligible, however, and they are present at higher solar latitudes than sunspots. For these reasons their rotation characteristics have been studied in detail.

If the photosphere and the chromosphere show rotation, what about the solar corona? This question is not easy to answer. The corona is so faint compared with the rest of the sun that it can be viewed only during a total eclipse of the sun or with the aid of the coronagraph: a telescope equipped with an occulting disk that blocks the light of the photosphere as the moon does (although not as effectively). In either case the exact connection between features of the solar disk and features of the corona is hard to determine. Moreover, the coronal features are so poorly defined that it is difficult to measure their size and position. The rotation of the corona may therefore be measured accurately only by correlating observations that extend over at least several months.

Richard Hansen, S. F. Hansen and Harold G. Loomis have measured the rotation period of the corona with a specially designed instrument attached to a coronagraph on the mountain Haleakala on the Hawaiian island of Maui, and they have found that the period varies somewhat from year to year. E. Antonucci and Leif Svalgaard of Stanford University have found that the rotation rate of the corona varies with the age of coronal features. The long-lived features



LINES IN SUN'S SPECTRUM ARE SHIFTED from their normal position because of the Doppler effect if there is a relative motion along the line of sight between the source of the lines and the observer. Since the sun rotates from east to west (*left*) the eastern limb of the sun (*A*) is approaching observers on the earth and the western limb (*B*) is receding. Thus spectral lines emitted by gas (*right*) on the eastern limb are shifted toward the blue region of the spectrum (*A*) and the lines emitted by gas on the western limb are shifted toward the red end (*B*). If the slit of the spectroscope is projected across the sun's equator, the lines on the spectrogram will be tilted. (In illustration the magnitude of tilt is exaggerated.) Spectral line from gas on central meridian (*C*) will not be shifted.

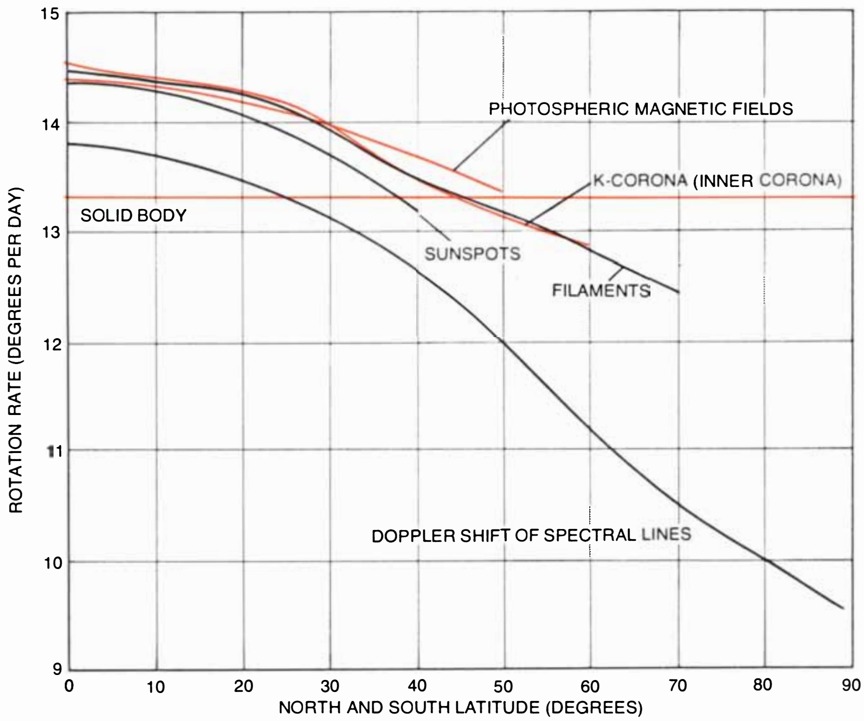
rotate almost as though they were part of a rigid body, whereas the short-lived features rotate much as the sunspots do.

In 1908 George Ellery Hale of the Mount Wilson Observatory found that sunspots are associated with strong magnetic fields. Only within the past two decades, however, has it been possible to reliably measure the weaker magnetic fields that extend over large areas of the solar surface outside the sunspots. Some years ago Václav Bumba of the Ondřejov Observatory in Czechoslovakia and I examined the large-scale patterns of such fields. We found that although individual magnetic features rotate at different rates depending on latitude in approximately the same way that sunspots do, the rotation of the overall pattern of the fields does not change with latitude over long periods of time and over a large range of latitudes. A few years later John M. Wilcox of Stanford and I confirmed these results and put them on a more quantitative basis. We found that the rigidly rotating patterns persist for many years. They are associated with interplanetary magnetic fields that have been measured near the earth, and they may represent a deep-seated magnetic framework of the sun.

William Henze, Jr., and Andrea K. Dupree of the Harvard College Observatory have measured the rotation of the sun with an experiment aboard *OSO-6* (the sixth Orbiting Solar Observatory). They observed the chromosphere and the corona in the light of spectral lines in the extreme ultraviolet region of the spectrum. Such photographs are roughly similar in appearance to the picture of the chromosphere made in the light of the hydrogen-alpha line, but the ultraviolet emission originates at higher elevations in the sun's atmosphere than the hydrogen-alpha emission. The data from *OSO-6* have yielded rotation rates that are somewhat slower than the rates derived from the other features I have mentioned. Curiously these rates, at least at low latitudes, closely resemble those derived from observations of the Doppler shift of spectral lines.

The wavelength at which a spectral line is formed depends on a transition between energy levels that is characteristic of the emitting species of atom. The wavelength at which the line is observed, however, depends further on the velocity along the line of sight of the source with respect to the observer. If the source and the observer are approaching each other, all the wavelengths will be shifted toward the blue end of the spectrum; if they are receding from each other, all the wavelengths will be shifted toward the red end. Thus a spectroscope aimed at a part of the sun that is turning toward the observer will detect lines that are shifted slightly toward the blue, and an instrument aimed toward a part that is turning away from the observer will detect lines that are shifted slightly toward the red. It is these Doppler shifts that can in principle be used to measure the speed of rotation of various regions of the sun.

The first Doppler-shift measurements of the sun's rotation were made by the German astronomer Hermann Vogel in 1871. Following on his work there were numerous other determinations, all of them plagued by the fact that when a spectroscope was aimed at the edge of the sun, light was scattered into the instrument from the sun's brighter central portion. The spectral lines of the scattered light blended with the lines from the region being observed and tended to



ROTATION RATES OF MARKERS DIFFER from the rotation rate of the gas of the sun's photosphere, or visible surface, as well as differing with latitude. Since all the tracers are associated with magnetic fields, this fact is interpreted to mean that the sun's magnetic field rotates slightly faster than the gaseous body of the sun itself. The rate of rotation for each marker is given in degrees per day of longitude on the sun. A curve showing what the rotation rate of the sun would be if it behaved as a solid body is given for comparison.

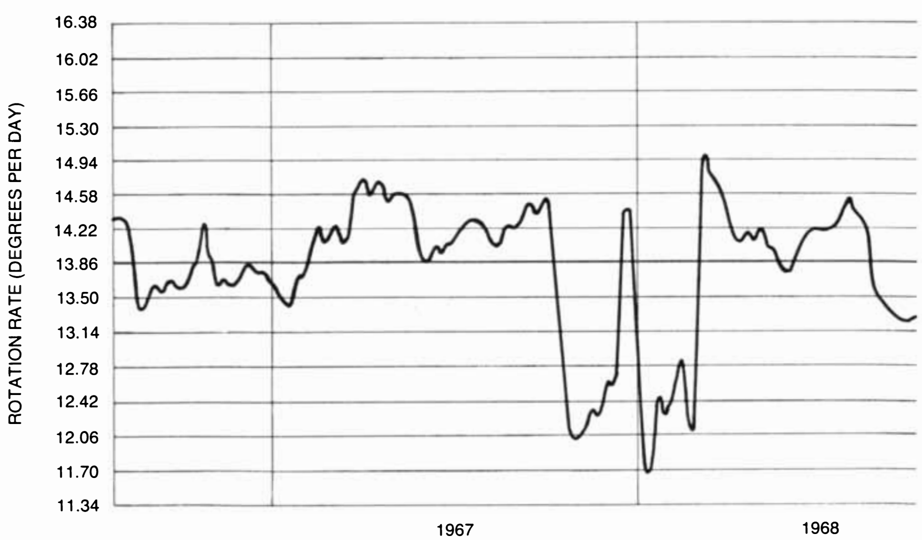
make the measured rotational velocities too low.

In 1966, however, measurements were undertaken with the solar magnetograph on Mount Wilson, a photoelectric scanning spectrometer. Actually measuring the rotation of the sun with this instrument was a by-product of an effort to monitor the magnetic fields of the sun. The solar magnetograph is so sensitive that it can detect a difference in velocity along the line of sight as small as 10 meters per second (a figure that happens to be equivalent to the top speed of a human sprinter). With such sensitivity it is now possible to measure the rotation of the sun close to the center of the solar disk, where the scattered-light problem is not as severe as it is at the disk's edge. Since 1966 the rotation of the sun has been monitored daily at Mount Wilson, and these observations constitute the bulk of the spectroscopic rotation data now available.

During the total solar eclipses of 1970 and 1973 John W. Harvey, William C. Livingston and L. Doe of the Kitt Peak National Observatory measured the rotation of the corona with spectroscopic techniques. They studied the coronal green line, which originates with iron atoms that have been stripped of many of their electrons by the corona's high temperature. These measurements showed little evidence that the corona's rate of rotation varies with latitude, although their accuracy is somewhat limited by the fact that parts of the corona also move randomly at substantial velocities.

The average rotation of the sun as a function of latitude, derived from various studies, is shown in the illustration at the left. In general the studies of the equatorial rotation velocity can be divided into two groups: the spectroscopic results and everything else. The sunspots, the filaments, the bright coronal streamers and the photospheric magnetic fields rotate approximately one day per rotation faster than the photosphere does. These fast-moving features have one thing in common: they are all associated with magnetic fields in the solar atmosphere. Sunspots have strong magnetic fields, filaments are known to lie between magnetic regions of opposite polarity and coronal streamers correspond to looping lines of magnetic force in the corona.

It thus appears that the magnetic fields rotate somewhat faster than the bulk of the photospheric gas does by about one day per rotation, or about 75 meters per second. (The rotation speed of the photospheric gas at the equatorial latitudes of the sun is about two kilometers per second.) It is possible, although it is by no means universally believed by solar physicists, that the magnetic fields rotate more rapidly than the photospheric gas does because they are connected to certain interior layers of the sun whose rotation rate is also fast. The magnetic fields, which are generally confined to tightly packed lines of force occupying only a small fraction of the surface area of the sun, can move



ROTATION RATE OF THE SUN VARIES with time as well as with latitude. That variation is shown by this illustration of the sun's equatorial rotation rate monitored over a

through the solar atmosphere like the periscopes of a fleet of submarines plowing through the ocean.

The rates of rotation of the visible features of the sun not only differ from the rate of the photosphere but also differ slightly from one another, depending on their latitude. Such differences are puzzling and for the present have no explanation. The uncertainties in the measurements of most of these rates increase at higher latitudes, and it is possible that at least some of the discrepancies are caused by systematic errors. By the same token slight differences in the spectroscopically measured rotation rate of the photosphere in the northern and southern hemispheres of the sun are near the limit of detectability, and for now they too must be set aside as possibly resulting from systematic errors.

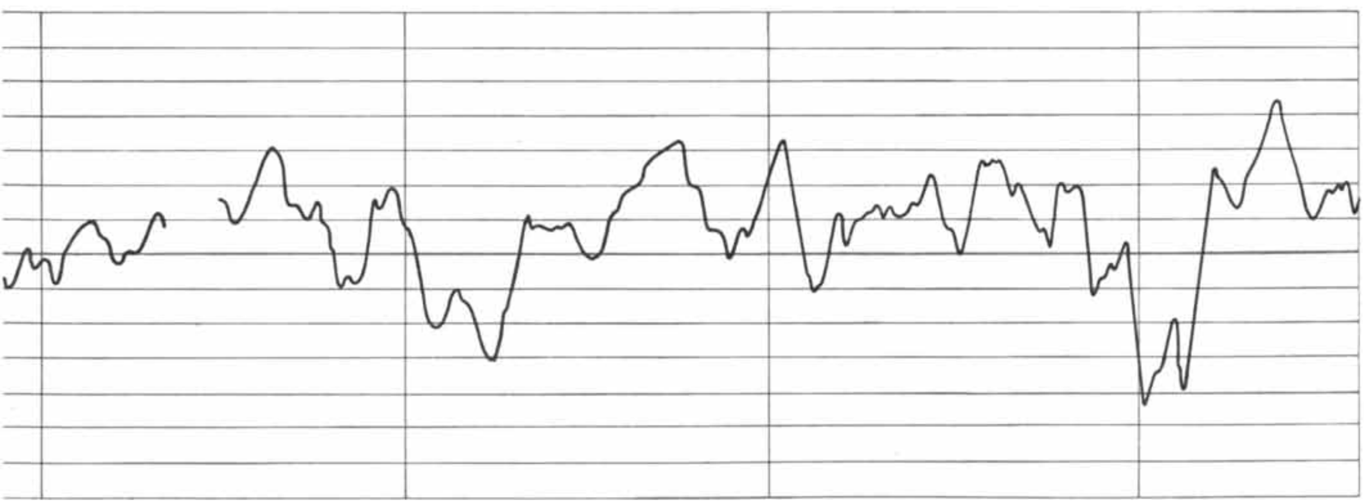
Spectroscopic observers early in this century generally agreed that the gases at higher altitudes in the solar atmosphere rotated significantly faster than those lower down. This view has since been discredited, not only because it seems highly unlikely but also because Livingston and Robert W. Milkey at Kitt Peak have recently made accurate observations that show it is untrue. They attribute the erroneous earlier results to the fact that in the spectra some of the absorption lines in the solar atmosphere blended with weak lines due to molecules in the earth's atmosphere, distorting the measurements.

Spectroscopic determinations of the rate of the sun's rotation have shown that it changes frequently. Over weeks or months the equatorial rotation rate may vary from the average by as much as 5 percent. These variations could be correlated with short-term variations in some aspect of solar activity, such as the number of sunspots, the mean strength of the magnetic fields or the frequency of solar flares. The first attempts to demonstrate such associations, however, have yielded no positive results. Over the past few years the spectroscopic data from Mount Wilson have shown a general tendency for the rotation rate to increase as solar activity has declined from the most recent maximum of the 11-year solar cycle in 1969. The increase has been only a few percent, and under the circumstances it is premature to conclude that there is a firm relation between the sun's rotational velocity and the phase of the solar cycle. Nevertheless, there is a strong possibility that such a connection exists, and solar observers will be examining the rotation rate with great care as the next maximum of the solar cycle approaches.

As yet there is no generally accepted theory as to why the sun's rotation should vary with latitude. The differential rotation, or any other large-scale phenomenon on the sun's surface, must be intimately related to the sun's internal structure and to the dynamics of the convective zone in its interior. The convective zone has a thickness equal to about 20 percent of the solar radius, and its upper boundary lies just below the layer of the photosphere where most of the spectral lines we see are formed. The gas in the convective zone comprises less than 1 percent of the total mass of the sun. Most of the mass is concentrated in the sun's dense, hot core, where thermonuclear reactions release the energy that is ultimately radiated from the photosphere. The energy is transmitted from the core up to the convective zone by means of radiative processes, that is, atoms within the sun absorb radiation and then reemit it. In the outer 20 percent of the sun's radius, however, the gas becomes unstable. Convective motions result, and almost all the energy in this region is transported by convection: hotter gases rise and cooler gases sink.

When we observe the sun, of course, we see only the layers of the photosphere above the convective zone. All that we know about the structure of the solar interior is inferred from the sun's mass, its surface temperature, its chemical composition and our theoretical knowledge of nuclear processes and the physical behavior of gases. We have no means of directly observing the rotation of the solar interior. Robert H. Dicke and his collaborators at Princeton University have nonetheless advanced a hypothesis about this rotation on the basis of their careful measurements of the sun's oblateness.

From the observed fact that the sun rotates once every 27 days one would predict that its poles would be flattened by about .01 second of arc out of the sun's apparent radius of 15 minutes of arc, corresponding to seven kilometers out of the sun's average radius of 700,000 kilometers. Such a minute quantity is very difficult to measure accurately because it is at least 100 times smaller

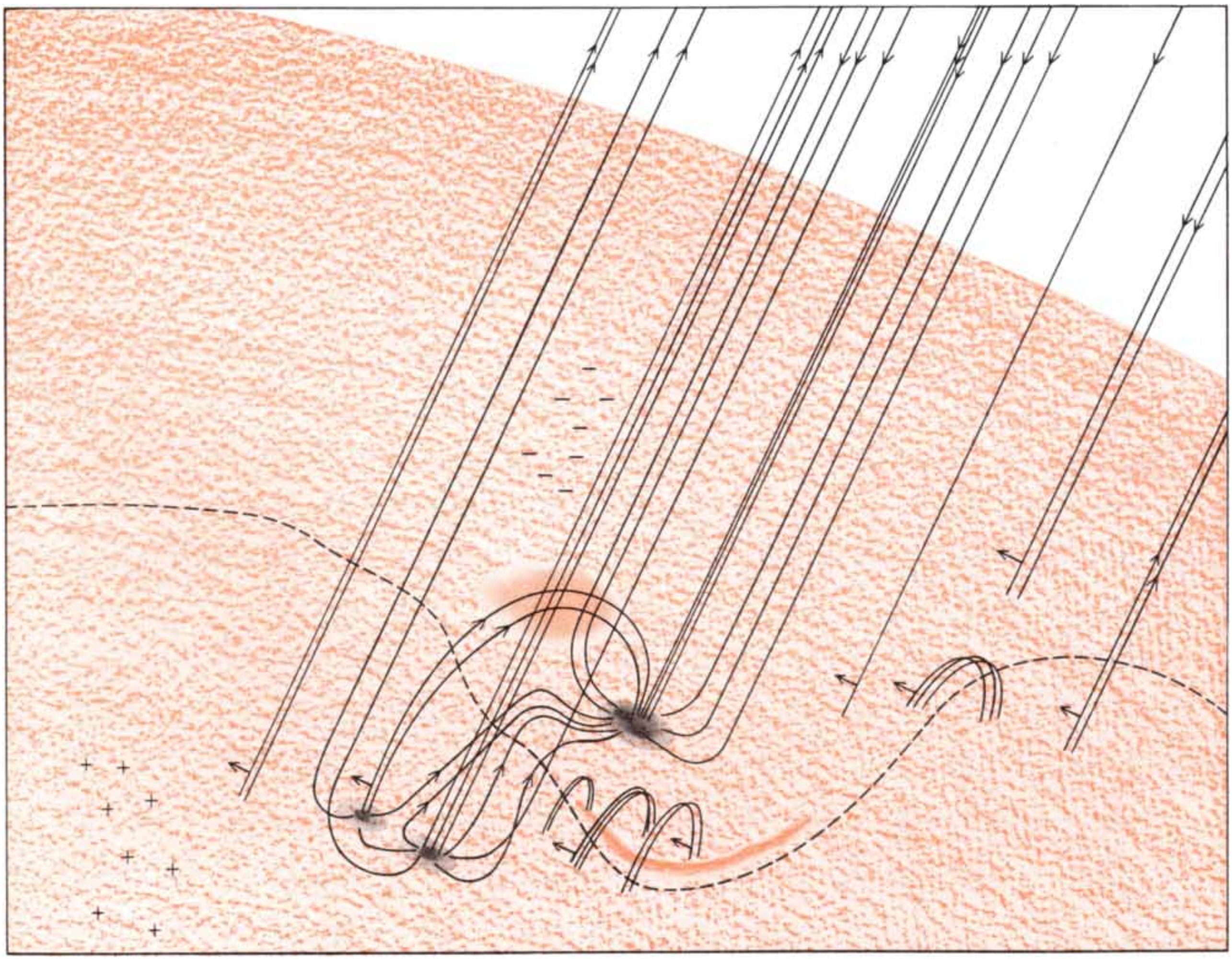


period of six years. The rate is plotted in degrees of longitude on the sun per day. The horizontal line at 13.86 degrees per day represents the average equatorial rotation rate over this period. Sometimes the rate varies suddenly for reasons that are not fully known.

than the blurring effects of the turbulence of the earth's atmosphere on the image of the sun. It is also smaller than errors introduced by imperfections inherent in the optical systems used to study the sun. In spite of these obstacles Dicke, working with an instrument of ingenious design, has measured the sun's shape and has concluded that its oblateness is five times as large as one would predict, namely about .05 second of arc. This relatively large oblateness, he explains, is due to the rapid rotation of the central core of the sun: about one turn per day. Such a rapidly rotating core will itself be oblate and will slightly alter the gravitational field at the surface of the sun, so that the surface too will be slightly oblate. Dicke's work has stimulated a controversy that has not yet been resolved. Recent attempts by another group have failed to confirm his results.

If the core of the sun is rotating rapidly, it cannot be tightly coupled to the convective zone. Ionized atoms are electrically charged particles that "feel" a magnetic field, and in a highly ionized gas such as the one that makes up the sun the lines of magnetic force can be considered to be mechanically coupled to the constituent atoms. Therefore if the lines of magnetic force are moving as the sun rotates, they will drag the ionized gas along with them. And if the lines of magnetic force thread their way from the sun's core through the convective zone, the two zones cannot maintain very different rotation rates for very long. In addition any exchange of material between a rapidly rotating core and a slowly rotating outer envelope will transfer momentum to the outer envelope and tend to decrease the difference in the two rotation rates.

Within the convective zone itself angular momentum is transferred easily and quickly in the radial direction by the continual convective motions. Moreover, the "wind" of solar particles that is constantly streaming away into space along the lines of force in the sun's magnetic field exerts a dragging effect that is strong enough to stop the rotation of the convective zone in only one million years. A million years is a short time on the scale of cosmic events, and we know the sun's surface layers cannot be decelerating that rapidly. If they were, and if the deceleration rate had remained constant for some time, only a few hundred million years ago the sun would have been rotating so fast that it would

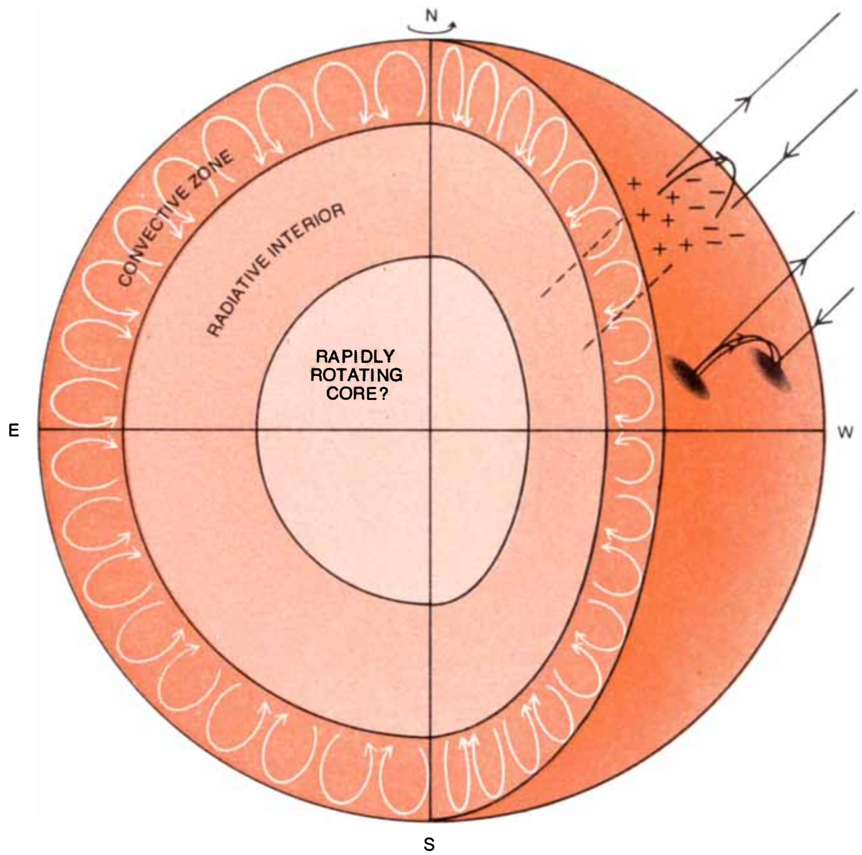


MAGNETIC FIELD LINES (*black*) at the surface of the sun (*color*) are confined to sunspots and to small bundles of lines outside spots. They are always closed loops, originating at the side of the sun with positive polarity and looping over a narrow neutral region (*broken line*) into an area of negative polarity. The long field lines extend far out into interplanetary space before they loop back to the surface. The small arrows at the base of the field lines show that they rotate about 75 meters per second faster than most of the photospheric gas; the gas not directly connected with a magnetic feature simply allows the lines to pass through. Ill-defined region centered on the field lines between sunspots is a coronal enhancement; above it streamers of the corona are particularly prominent.

have thrown off an appreciable fraction of its mass by centrifugal force. Since the dragging force of the solar wind is not strongly slowing the rotation of the convective layer, much of the force must be expended in slowing the denser matter below the convective layer, although not necessarily the matter in the core.

In this general picture the lines of force in the sun's magnetic field are firmly connected to deeper layers of the sun where the rotation rate is higher than it is at the surface. The lines of force are dragged through the photosphere by their roots, although the depth of these roots has not been established. An alternative explanation for the difference between the rotation rates of the magnetic fields and the rotation rate of the photosphere is that there is a large-scale pattern of circulation in the sun that somehow (it is not clear exactly how) moves the field lines preferentially in one direction. On a small scale of perhaps 1,000 kilometers there is a circulation pattern on the solar surface called granulation, and on a slightly larger scale of about 30,000 kilometers there is a pattern called supergranulation. George W. Simon of the Sacramento Peak Observatory has suggested that there might be an analogous pattern on a scale of about the radius of the sun. Observational evidence for such a giant circulation pattern is skimpy, but perhaps that is not surprising, because the velocity of the flows in such a pattern is expected to be quite low—only a few meters per second.

There are several theoretical models that attempt to explain why the angular velocity of the sun varies with latitude. None of these models, however, is based on exact solutions of all the physical equations involved. Solar physics suffers from the lack of a definitive theory of turbulent convection in a compressible gas. The models I shall discuss are for the most part ingenious combinations of solutions for large-scale motions in simplified physical cases and assumptions about the large-scale effects of small-scale processes.

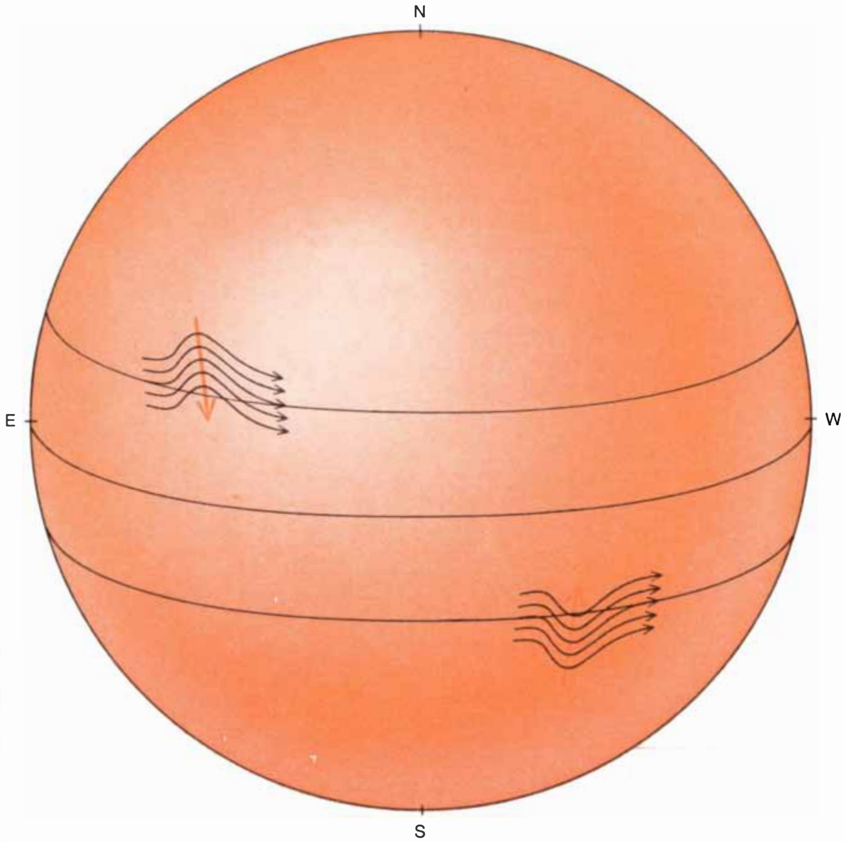


INTERIOR OF THE SUN in this cutaway view shows the convective zone and the hypothesized rapidly rotating core. The sun's energy is generated by thermonuclear reactions in the core and is transported toward the surface by means of radiative processes: atoms of the gas absorb, reemit and scatter the radiation. At a point about 20 percent of the radius from the surface the gas becomes unstable to motions along the radius and the energy is transported by convection: hot gases rise and cool gases fall. The roots of the magnetic field lines extend through the convective zone, although the depth to which they reach is not known. The lines that extend into interplanetary space carry with them a steady flow of ionized gas: the solar wind. Entire pattern of the magnetic fields rotates with the sun, and the effect of the solar wind is to exert a drag on rotation of outer layers of sun.

Ludwig Biermann of the Max Planck Institute for Physics and Astrophysics in Munich has suggested that if the viscosity of the convective gas in the sun is not the same in all directions, the result can be differential rotation. Biermann's colleagues have extended this notion into a more refined model. If the viscosity of the solar gas in the radial direction is less than that in the plane perpendicular to the radial direction, the convective circulation patterns result in a net transport of angular momentum toward the solar equator because the gas moving radially toward the equator carries more angular momentum than the gas moving radially toward the poles. Hence the energy maintaining the high equatorial rotation rate comes from the convective motions. One disadvantage of this model is that it requires the inner layers of the sun to rotate slower than the outer layers, whereas the evidence from the rotation of the magnetic tracers points to the opposite conclusion.

A second model, first suggested by Fred W. Ward of the Air Force Cambridge Research Laboratories, posits that there are surface circulation patterns in the solar atmosphere that are analogous to patterns in the earth's atmosphere known as Rossby waves. Such patterns would transport angular momentum toward the solar equator because of the way in which the waves are slanted [*see illustration on next page*]. The waves moving toward the equator carry more angular momentum than the waves moving toward the poles, and thus the waves moving toward the equator support the faster equatorial motion. Here one considerable problem remains: to explain why the waves exist and how they are maintained. One suggestion is that they are maintained by a temperature gradient on the sun: the poles are hotter than the equator. Such a temperature gradient has not been observed. Recently, however, a wave pattern similar to the one required for this model has been detected by R. G. Hendl of the Massachusetts Institute of Technology on the basis of the observations made at Mount Wilson, lending support to the Rossby-wave hypothesis.

A third model relies on the notion of the giant convection cells. According to



ROSSBY WAVES is one model proposed for explaining why the sun rotates differentially. The curved arrows of the Rossby waves (*gray*) are streamlines, representing the motion of the gas on the sun's surface. Because of the shape of the streamlines the motion of the gas toward the equator (*arrows in color*) carries more angular momentum (momentum of rotation) toward the equator than toward the poles. The net effect is to transfer momentum.

theoretical calculations made by B. R. Durney and Peter A. Gilman at the National Center for Atmospheric Research, the sun is likely to generate large-scale convective circulation in long rollers that move predominantly from east to west near the surface. The rollers can transport momentum to the equator if their motions are not exactly east to west. This model has had some success in reproducing some of the characteristics of the sun's differential rotation. It suffers, however, from the disadvantage that it too calls for a lower rotation rate below the surface than at the surface. An additional disadvantage is that a sizable flow from north to south is also needed to make the model work. Although some observers, notably H. H. Plaskett of the University of Oxford, have reported detecting such motions, sensitive observations made at Mount Wilson do not confirm their existence.

K. H. Schatten of the Victoria University of Wellington in New Zealand has suggested that the differential rotation of the sun results not from the acceleration of the equatorial region but from the deceleration of the regions at higher latitudes. He argues that the lines of magnetic force extending into interplanetary space originate preferentially at the high latitudes, so that the dragging effect of the solar wind will slow those regions more. Hence it is not necessary to transfer angular momentum to the equator because it is automatically extracted from the high latitudes.

At the moment it is not possible to say which, if any, of these models gives the correct explanation. The fertile minds of theoreticians seem able to devise many mechanisms to explain the differential rotation of the sun. When the explanation is known, it will greatly assist our understanding of the structure and rotation of the solar interior and, through the connecting medium of the magnetic fields, our understanding of solar activity. Moreover, since the sun is a Rosetta stone for learning about the billions of other stars in the universe, the explanation will also aid investigations into the nature of stars and into the evolution of the galaxy.

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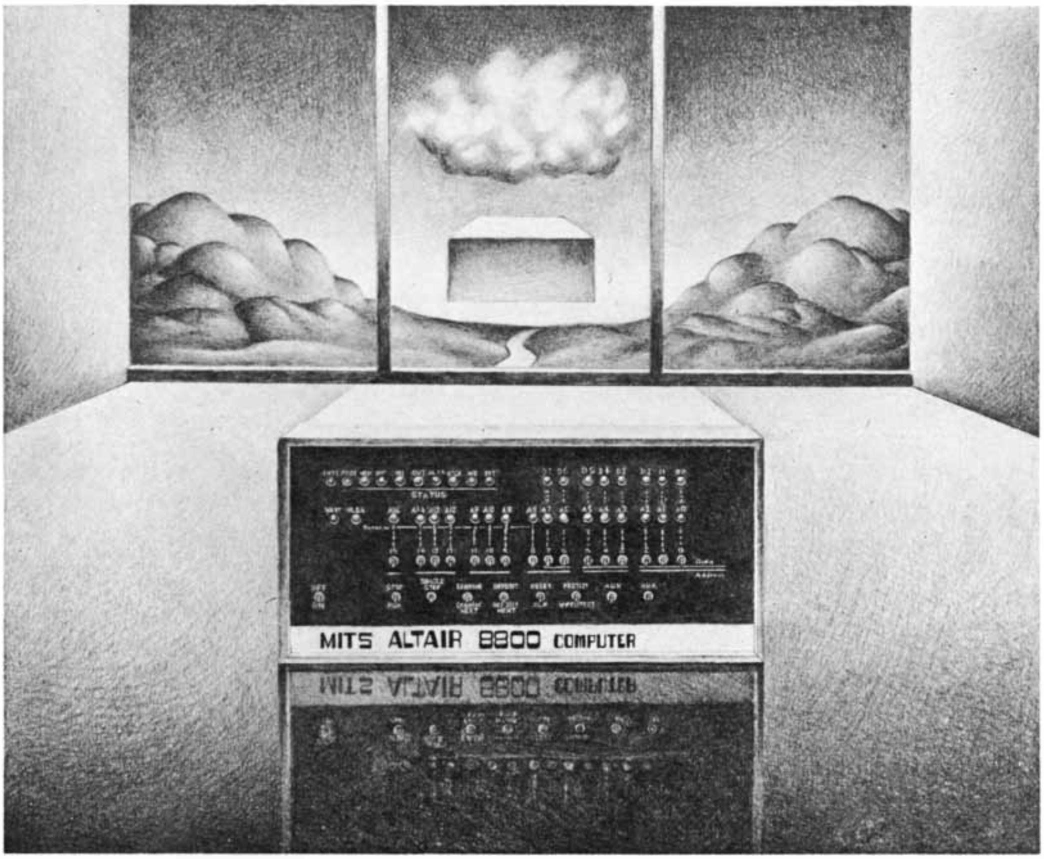

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NOTE: Altair Computers come with complete documentation and operating instructions. Altair customers receive software and general computer information through free membership to the Altair User's Club. Software now available includes a resident assembler, system monitor and text editor. Basic language soon to be available

Prices and specifications subject to change without notice. Warranty 90 days on parts for kits and 90 days on parts and labor for assembled units.

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