THE SUN'S MAGNETIC FIELD, 1952–1954

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ABSTRACT

More than 450 magnetograms, showing the distribution, intensity, and polarity of weak magnetic fields (> 0.3 gauss) on the sun have been obtained with the solar magnetograph over a two-year period. This interval includes the recent minimum of solar magnetic activity. The records show a pattern with a fluctuating fine structure and certain large-scale regularities.

General magnetic field.—Consistent evidence is found for a general field, predominantly dipolar, with polarity opposite to that of the earth. The mean intensity is of the order of 1 gauss. The general field is usually limited to heliographic latitudes greater than about $\pm 55°$; it has a varying fine structure and shows remarkable random fluctuations in effective intensity and extent. There seems to be no prevailing obliquity between the magnetic and rotational axes. The total flux is estimated to be nearly 10^{22} maxwells.

Bipolar magnetic (BM) regions.—In the lower latitudes the stronger magnetic effects appear as contiguous areas of opposite magnetic polarity, as if loops of a submerged toroidal field were occasionally brought to the surface by rising material. The BM regions obey Hale's laws of sunspot polarity, but spots are comparatively rare, occurring, when at all, within the BM regions while they are young. *Ca* II *plages* are observed where the field intensity is greater than about 2 gauss. Hydrogen filaments occur around the borders of BM regions or, alternatively, seem to divide the region into parts of opposite polarity. As the regions age, they generally expand, showing a decrease in field intensity, and disintegrate until lost in the background of irregular weak fields. There is much diversity in total magnetic flux, duration, area, and course of development.

Unipolar magnetic (UM) regions.—Occasional extended magnetic areas of only one outstanding polarity were recognized. The most prominent UM region of 1953 had an intensity $\lesssim 3$ gauss and a duration of many months; it may well have been related to a prominent sequence of 27-day-recurrent terrestrial magnetic storms. UM regions may be remnants of disintegrating BM regions. We suggest that UM regions may be identified as the heretofore hypothetical "M" regions of Bartels.

Repeated tracings of the same area of the sun at intervals of a few minutes show changes of the order of 1 gauss in the fine structure of the magnetic pattern within a half-hour.

The observations provide objective evidence for the heretofore inferential hypothesis that magnetic fields are fundamental to sunspots, *plages*, prominences, chromospheric fine structure, bright coronal emissions, and, probably, regions of strong radio emission. Several solar phenomena can be synthesized on the proposition that neutral but ionized corpuscular streams are continually being ejected from all turbulent regions of the surface characterized by coherent magnetic fields of average intensity $\frac{1}{2}$ gauss or more. A hydromagnetic model, based on chromospheric spicules, is proposed for such ejection.

INTRODUCTION

The observations of weak solar magnetic fields discussed in this paper were made in the preminimum and minimum years of the solar cycle between August, 1952, and November, 1954. They were obtained with the solar magnetograph, an instrument utilizing the Zeeman effect for the measurement and recording of weak photospheric magnetic fields, which has been described previously by one of us (H. W. Babcock 1953). The instrument measures $H \cos \gamma$, the component of the field in the line of sight, with a precision of a fraction of 1 gauss. An electo-optic analyzer for circular polarization precedes a grating spectrograph of high dispersion and resolving power; at the focus, a double-slit photoelectric detector measures the phase and amplitude of oscillation between the polarized components of the chosen spectrum line. All the results reported here were obtained with the line λ 5250.216, (0), 3 of *Fe* I.

The magnetograph scans the disk of the sun in a series of parallel traces and records conformally the location, polarity, and intensity of the photospheric magnetic fields on magnetograms, such as are reproduced in Figures 1–4. On the records, north is the top, east at the right. An upward deflection of the signal trace with respect to its fiducial line indicates that, for the region on the slit, the magnetic vector is positive in sign (toward the observer), and vice versa. The calibration of the deflections is discussed in a subsequent section, but, in general, a deflection of one trace-interval is equivalent to about 1 gauss. It should be borne in mind that the record indicates the field intensity in a strip centered on the fiducial line, not in the area under the curve. This type of recording was adopted because of its convenience from the technical standpoint. All the available information is presented, and the magnetograms can readily be interpreted. The records can be transformed into contour maps of magnetic intensity, perhaps with different colors to indicate magnetic polarity, but the process adds nothing new.

The present report is based on a sequence of 450 magnetograms, together with certain comparisons of the solar magnetic data with Mount Wilson spectroheliograms, with preliminary synoptic records of coronal line intensities published by the High Altitude Observatory, and with the geomagnetic planetary index, K. It has become apparent from a survey of the records that the weak fields recorded by the magnetograph provide one of the most sensitive indicators of solar activity. So much detailed information is to be found on the magnetograms that a verbal description of it is an inadequate substitute for an examination of the records themselves. A limited number of selected magnetograms and short sequences have been reproduced from the original 35-mm negatives in Figures 1–4. They are referred to by the individual dates. In almost all cases the U.T. of observation may be obtained by adding 0.8 day to the recorded calendar date.

The magnetograms reveal information of significance on the sun's general magnetic field, on hydromagnetic turbulence in the photosphere, on the development and life-history of "centers of activity" (including sunspots), and on certain solar-terrestrial phenomena. One of the chief impressions gained is that the photospheric magnetic fields have a prominent fine structure, showing fluctuations with time; this fine structure is probably closely related to turbulence of the highly conducting material with which the fields are associated. Many of the larger-scale magnetic patterns are quite complex, in spite of the fact that the general level of solar activity has been low during the years covered by these observations. Among the regular features of the weak solar magnetic fields, however, three are outstanding.

1. There has been consistent evidence, as previously reported (Babcock and Babcock 1952; Babcock 1953; Babcock and Cowling 1953), for a "general" field of the sun in high heliographic latitudes. The polarity is positive in the north, negative in the south (opposite to that of the earth's field). The intensity of the general field near the poles is of the order of 1 gauss on the average, although there are appreciable fluctuations in the intensity of the effective component and in the lower limit in latitude.

2. Bipolar magnetic (BM) regions, sometimes of vast extent, occur in and near the sunspot zones; they obey the laws of magnetic polarity established for the preceding and following sunspots in the northern and southern solar hemispheres, in a given cycle, by G. E. Hale and his associates (1919). Visible sunspots have been relatively infrequent and short-lived, but when they occur, they are within these BM regions.

3. The heliographic latitudes in the vicinity of $\pm 45°$ have been, on the average, more nearly free of magnetic fields than any others.

During the period covered by the observations, various improvements have been made in the apparatus, but the principles of the instrument, including the method of recording with a cathode-ray tube and a camera, have been retained throughout. In the original form of the instrument, the parallel traces across the disk from west to east were made by allowing the sun's image to drift. Between August 1, 1952, and February 19, 1953, 101 magnetograms were obtained in this way. At the start, the analyzer incorporated a rotating quarter-wave plate, which, unless very carefully adjusted, was capable of introducing systematic errors into the records. But in October, 1952, all moving parts were eliminated from the analyzer, and the electrically excited birefringent crystal was

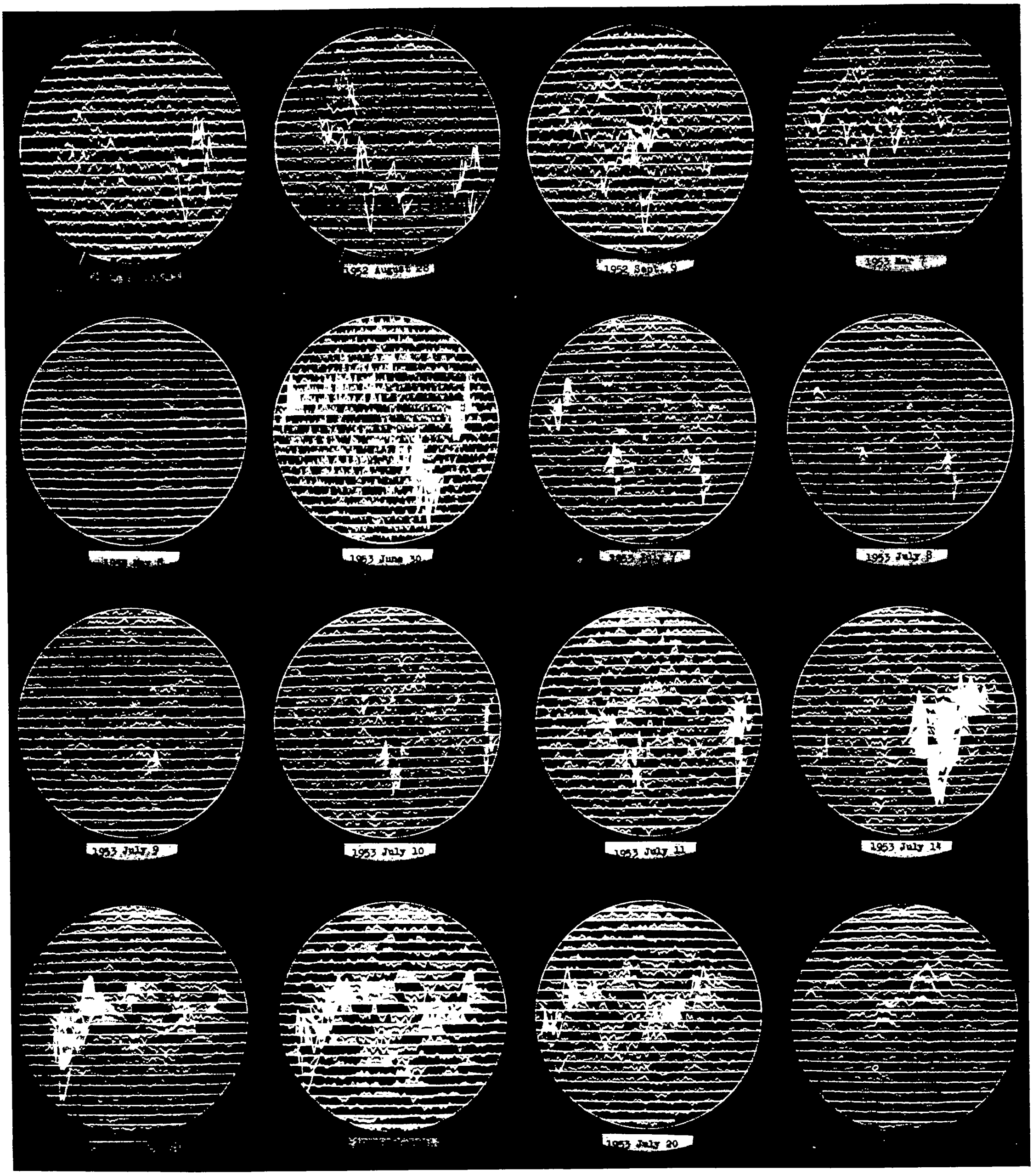

FIG. 1.—On the first three records the position of the poles of rotation is indicated. On all subsequent records the central meridian is vertical. All records were made with a time constant of about 3 seconds, except that of June 30, 1953, which was 1 second. Note the opposite characteristic polarity of BM regions in the northern and southern hemispheres; also the UM region near the c.m. on July 22. Calibration in gauss per trace-interval is: June 30, 0.9; July 7, 1.2; July 8, 1.2; and, by rows: 1.3, 1.3, 1.0, 1.0; 1.5, 1.1, 1.3, 1.4.

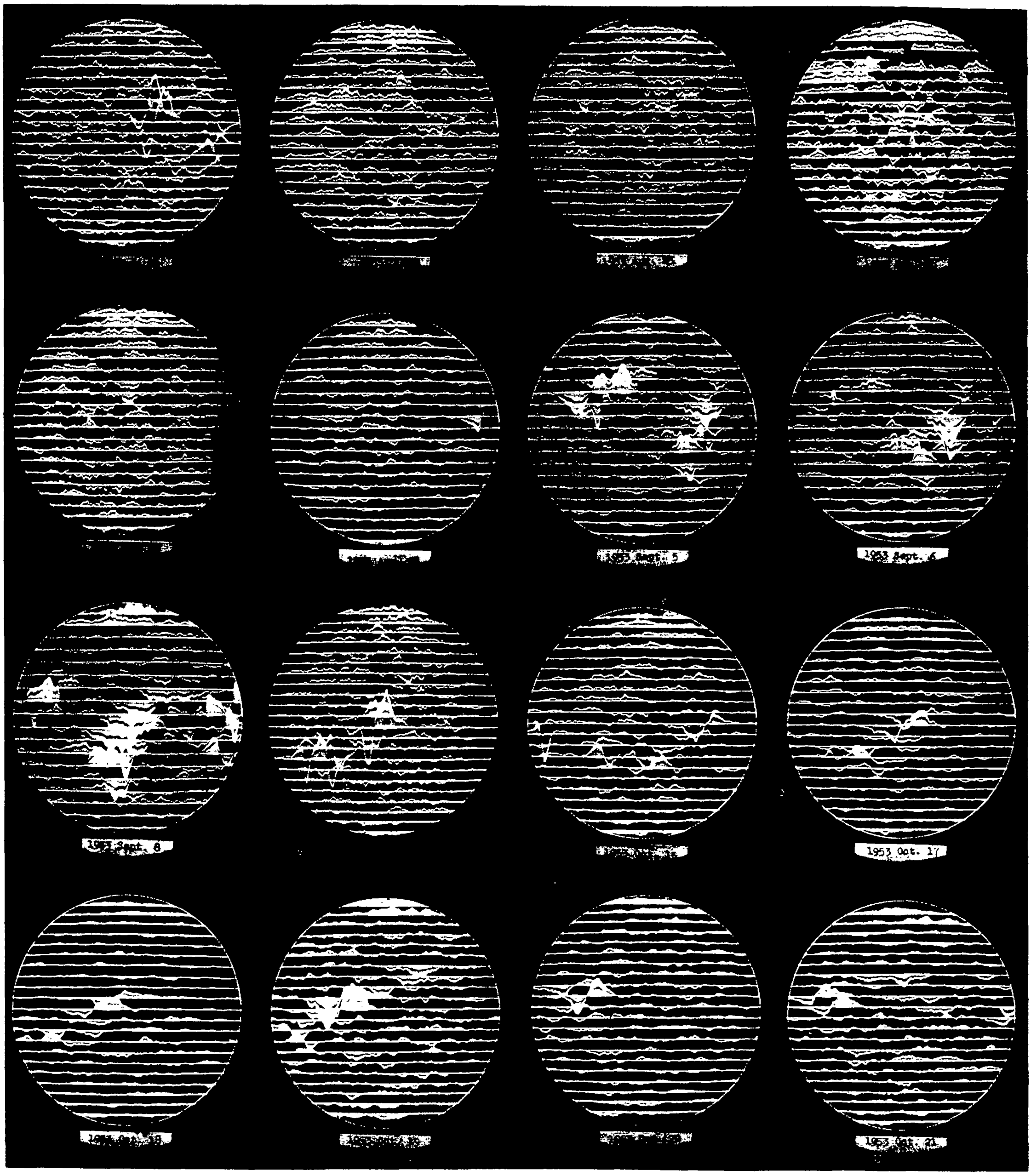

Fig. 2.—Note the unusually strong north polar field on August 26 and 27, 1953; also the UM region on September 8. Calibrations by rows are: 1.0, 1.0, 1.1, 1.1; 1.0, 1.4, 1.5, 1.4; 0.9, 1.0, 1.5, 1.3; 1.5, 0.8, 1.0, 1.3. The amplitude of the deflections is quantitative, but the degree of intensification of the trace on large deflections is arbitrary.

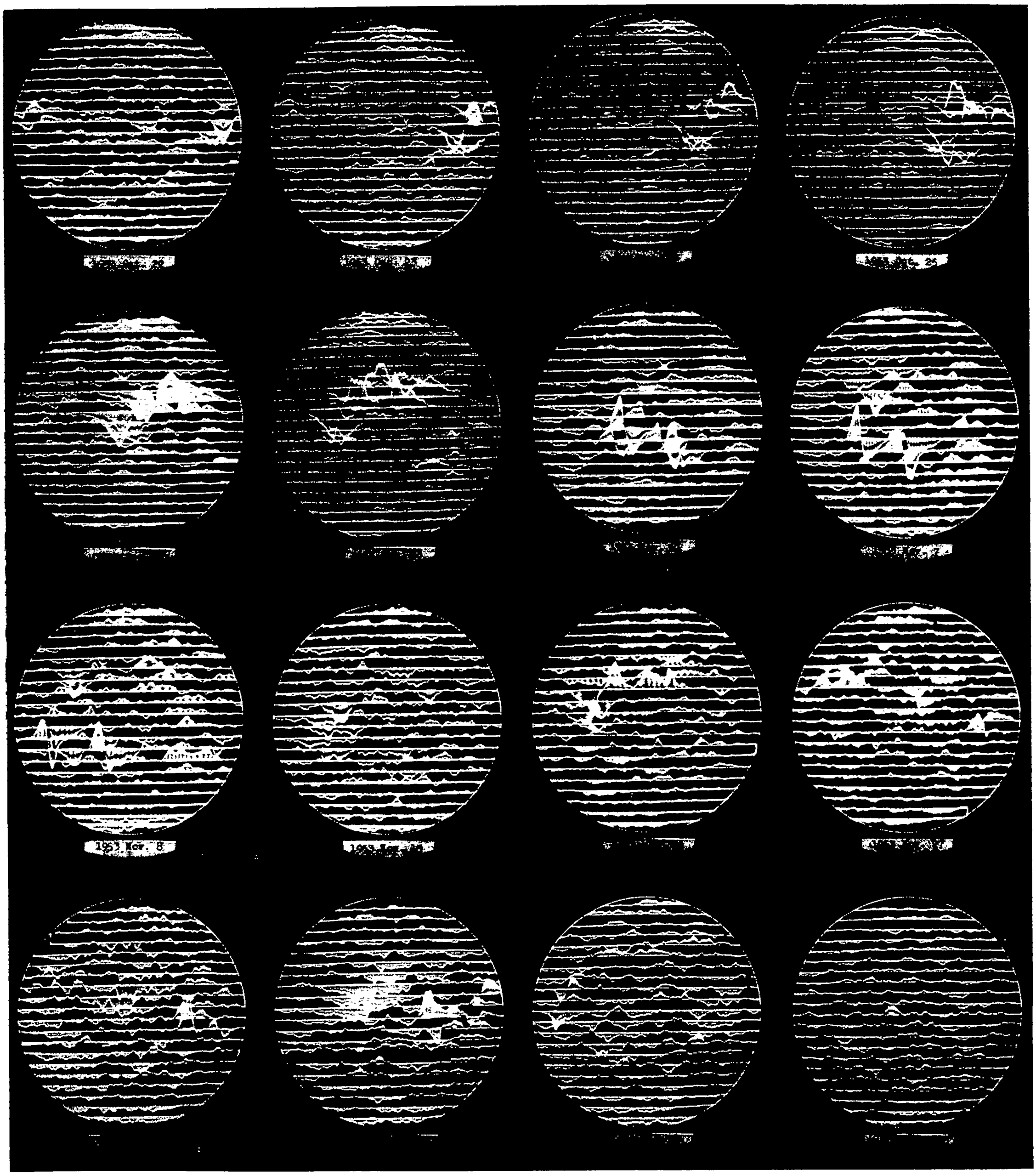

FIG. 3.—The traverse of an extended BM region is shown in the sequence of October 22 to October 28, 1953. The record of December 7 is unusually quiet, even for the months of minimum solar activity. Calibrations are: 0.9, 0.9, 1.0, 0.9; 0.9, 0.8, 1.4, 1.3; 1.1, 1.1, 1.3, 1.3; 1.3, 1.1, 1.0, 1.4.

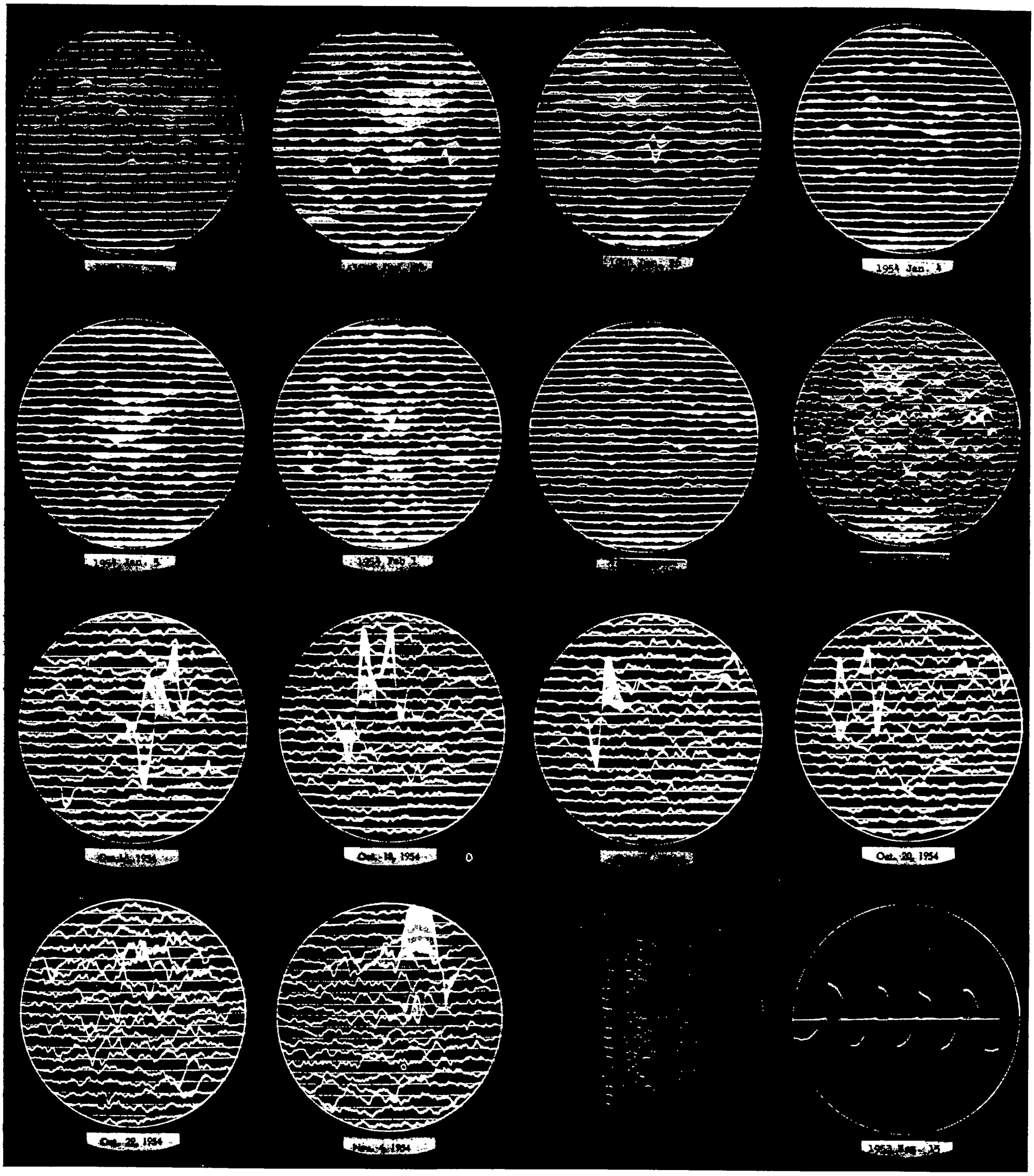

FIG. 4.—Weak but extensive UM regions are seen on December 24, 1953, and January 5, 1954. Note the "old-cycle" BM region in low north latitude on October 19, 1954, and the peculiar unbalanced BM region of "new polarity" in a high north latitude on November 4. The repeated chords of March 26, 1954, show reproducibility of deflections; minor changes are better shown in Fig. 8, *e*. The lowest trace of March 26 is "noise" alone. The record of November 15, 1953, shows calibration deflections equivalent to 5 gauss. Calibrations by rows are: 1.2, 1.0, 1.2, 1.2; 0.9, 0.9, 0.8, 0.6; 0.9, 0.9, 0.9, 0.9; 0.8, 0.8.

put into use. In the spring of 1953 the self-synchronous scanning system was placed in operation. With this system, the traces are always made perpendicular to the central meridian of the sun. Between February 19, 1953, and October 28, 1954, 350 magnetograms were obtained. During the course of these observations, occasional small improvements in sensitivity were made, the most important being the installation in February, 1954, of a superior grating that approximately doubled the available light and retained a resolving power of 600,000. All these changes resulted in a gradual improvement in the quality of the records.

Calibration.—The sensitivity was frequently checked by making calibrations according to the method of artificial deflections outlined earlier (Babcock 1953). A sample calibration record is shown in Figure 4. Also, during the course of each observation, the brightness of the solar image was measured with a simple photoelectric meter. This provided a basis for the calibration of the individual magnetograms in terms of gauss per interval between traces. Calibrations are available for 294 magnetograms taken between June 20, 1953, and October 28, 1954. One of the greatest variables is the low-level atmospheric transparency in Pasadena, where the observations were made. Records made on days of inferior transparency, when the light was reduced to a fraction of normal intensity, are recognized by the relatively low noise level and generally low deflections. On typical magnetograms, the calibration of the deflections is about 1 gauss for the interval between traces, and the noise level is about 0.1 gauss (r.m.s.). After the completion of each magnetic scan of the sun, it has been customary to make a "noise record" by switching off the exciting voltage to the birefringent crystal and permitting the instrument to make one or more traces across the disk of the sun without change of any other adjustments. Such noise traces show the small deviations due to random shot noise in the photomultipliers and would also show any systematic error or "signal bias" if such were present. There has been a satisfactory absence of systematic error on practically all magnetograms.

Heliometric resolution.—The diameter of the sun's image is about 40 cm and the length of the scanning slit is 15 mm. Thus the instrument averages the magnetic effect over 70 seconds of arc, corresponding to a distance of 52,000 km on the projected disk, in the general direction of the central meridian. In the direction of scanning (perpendicular to the central meridian) the effective resolution is determined by the time constant chosen for the electrical smoothing circuits. To obtain a suitable signal-to-noise ratio at the light-level available, the time constant is usually made about 3 seconds. At the customary rate of scanning, the motion of the slit with respect to the image is about 38 seconds of arc (28,000 km) in this interval of time. When conditions warrant, a slower rate of scanning is desirable, because there is no doubt that many of the finer details of the magnetic pattern are unresolved on the usual magnetograms. Tests with and without scanning have shown that small magnetic areas of diameter 30 seconds of arc and having an average field of 5 gauss may show on the standard magnetograms an indicated field of only 1 gauss, because of the smoothing effects mentioned. But the resolution is such that more extensive fields are recorded without serious reduction in scale, and it is these that are the first concern of this paper. The magnetogram of June 30, 1953, was made with a time constant of only 1 second and shows more fine structure, but the noise level is inevitably higher.

Studies of the position of filaments as related to magnetic areas and of the details of magnetic regions in general are limited, on the present magnetograms, by the heliometric resolution and by imperfections in the instrumental tracking on some of the records. Occasional errors of position as great as 5 per cent of the solar radius are present. Also, since alternate traces are made in opposite directions, the time constant of the smoothing circuits introduces a slight alternating asymmetry into the traces. This need for higher fidelity in recording the fine structure of the sun's magnetic pattern, as well as the desirability of a still better signal-to-noise ratio, indicates that the magnetograph is capable of much further development. The attainment of these ends is only a matter of practical design.

Sunspot fields.—The magnetograph was designed primarily for measuring and recording weak magnetic fields apart from sunspots, of intensity less than 10 gauss. In the present series of records, no attempt has been made to obtain quantitative results on the much stronger magnetic fields of sunspots themselves, although these naturally produce large deflections. Spots are small compared to the length of the slit and are dark compared to the photosphere; also the amplifier becomes saturated by signals stronger than about 10 gauss. In comparison to the very extended photospheric fields revealed by the magnetograph, sunspots may, in a certain sense, be regarded as almost incidental, being local regions in which the magnetic field is sufficiently strong, according to current ideas (Biermann 1941), to inhibit small-scale convection. This results in darkening through a diminution of energy outflow.

The photoelectric measurement of sunspot fields should be quite feasible in good seeing, however, by using a suitably short slit and by employing a spectrum line rather insensitive to the Zeeman effect, in order that the magnetic splitting of the line shall remain small relative to the half-width of the line profile and to the separation of the two exit slits.

THE GENERAL MAGNETIC FIELD

A weak field in high heliographic latitudes, of positive polarity in the north, negative in the south, has been shown almost consistently by the magnetograph since August, 1952, when good sensitivity was first obtained. Evidence for the polar fields is found on most of the records made under good atmospheric conditions. On days when low atmospheric transparency reduces the light-level and the effective sensitivity by a factor of 2 or more, the weaker fields are poorly recorded. Even under such conditions, however, the polar fields can almost invariably be detected if the scanning is stopped and the sun's image is held stationary, with the slit near the north or south pole; this permits a longer instrumental time constant to be used. In general, the polar fields are detected only in heliographic latitudes higher than about $\pm 55°$, but the lower limits in latitude are variable and irregular. When magnetograms made on days of good transparency are compared and when the calibration of all records in gauss per space is taken into account, it is found that there are appreciable fluctuations in the effective intensity of the polar fields, in the pattern of their fine structure, and in their lower limits in heliographic latitude.

Occasional small polar faculae have been seen during the interval under discussion; while these may be related to local field concentrations, they seem to have no essential bearing on the rather extensive polar fields. There appear to be no features on the usual Mount Wilson spectroheliograms in the light of *Ca* II or of hydrogen that can be related to the weak magnetic fields near the poles of the sun; but, as will be shown in a later section, there is such a relationship for the stronger localized magnetic fields found in the lower heliographic latitudes.

If due allowance is made for limb darkening, an average value for $H \cos \gamma$, the component of the field in the line of sight, is about 1 gauss near the poles. Because of the fluctuations and irregularities already mentioned, it is difficult to specify a more precise value. These small-scale fluctuations are plausibly related to turbulent convection, which is continually distorting and "bunching" the lines of force of the magnetic field in the photosphere. For the mean direction of the lines of force we have adopted here the direction of the coronal features known as "polar tufts" or "plumes," which arise from the same high-latitude regions of the sun. (This is open to some question, for, while the magnetic forces may dominate in the corona, they may not do so in the photosphere.) It is probable, then, that the mean effective value of γ is about 60°. The probable mean intensity of the general field of the sun for the last 2 years has therefore been of the order of 1 or 2 gauss near the poles.

The lines of force are most plausibly imagined as passing through the main body of the sun from the vicinity of one pole to the other; hence the field is a property of the sun as a whole, and it appears proper to speak of a general magnetic field, even though evidence for it is usually limited to the polar regions. Factors that lead to confidence in the reality of the general field, as revealed by these observations, are as follows:

1. The deflections near the heliographic poles, while small, are usually several times as great as the largest instrumental noise fluctuations (particularly with a stationary image).
2. The magnetic deflections disappear when the exciting voltage is removed from the birefringent ADP crystal of the polarizing analyzer.
3. The magnetic deflections are reversed in polarity if the azimuth of the birefringent crystal is changed by 90° from its standard position.
4. The indicated field intensity shows a fine structure, varying from point to point on the disk; and within short intervals of time the local deflections are reproducible at will as a function of position.

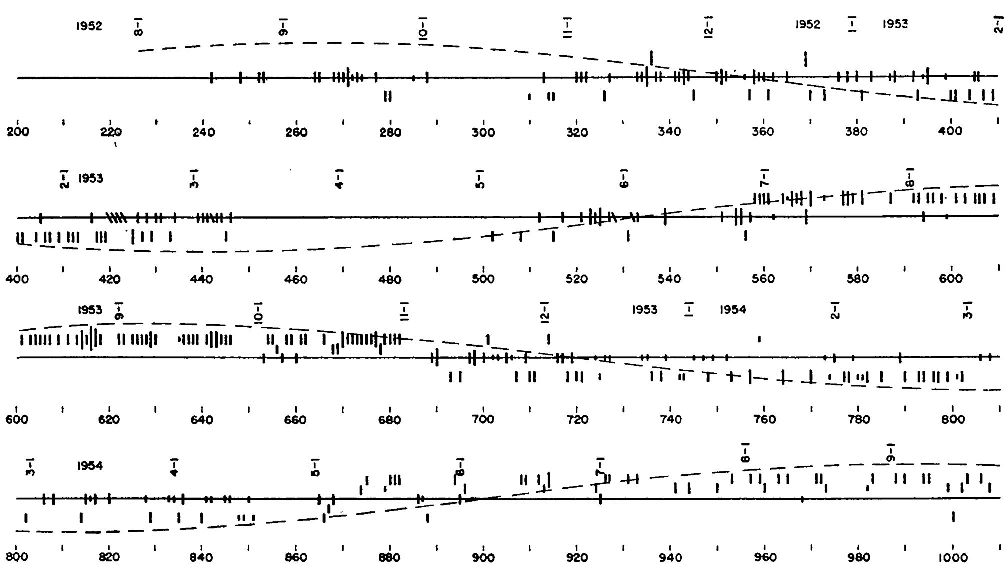

FIG. 5.—If the north polar flux appears greater than the south, a mark is placed above the horizontal axis, and vice versa. Abscissas are Julian days minus 2424000, where the first of each month is alsc indicated. A sine-curve indicating the heliocentric latitude of the earth, B_0 (amplitude 7°2), has been drawn in. The magnetic-flux ratio (N/S) shows a general dependence on the sign of B_0, as might be expected; but large random deviations are superposed. No evidence is found for obliquity between the magnetic and rotational axes of the sun. The B_0-curve may be used, incidentally, for estimating the heliocentric latitude of the center of any of the magnetograms of Figs. 1–4.

5. Schuster's (1892) assumption, that the polar tufts of the corona suggest the lines of force of a general magnetic field, is still plausible.
6. The ratio of the mean observable magnetic flux for the north and south poles shows an annual variation that appears to be correlated with B_0, the heliocentric latitude of the earth. This effect is discussed in the following paragraph.

On many occasions it has been found that the total apparent magnetic flux in the vicinity of one of the sun's poles is greater than that at the other by a factor of the order of 3 or more. Without at first attempting to evaluate the intensities quantitatively, the magnetograms were inspected and classified as to whether the total apparent fluxes were about equal at the two poles, or, if obviously unequal, which was the stronger. The results are displayed in Figure 5, where, if the north polar deflections were stronger than the south, a mark for the day in question was placed above the horizontal axis, and vice versa. As a matter of secondary interest, days of unusually strong or weak polar field intensity were indicated by longer or shorter marks. A definite seasonal trend appears, although this is masked in part by daily fluctuations, apparently irregular, that may be as great. For comparison, a sinusoidal line, representing B_0, the heliocentric latitude of the earth, has been drawn in. The annual variation of B_0 not only affects the ratio of the the visible areas of the respective magnetic "polar caps" of the sun above $\pm 60°$, but in the same sense it affects γ and the effective component of the field. Except for the first three months (when, in observing, little attention was given to the flux ratio at the poles), the underlying correlation between the sign of the flux ratio and the sign of B_0 appears significant. This emphasizes both the reality of the polar fields and their restriction to high heliographic latitudes.

With reference to Figure 6, we have made a rough computation of the extreme ratio to be expected for the apparent north and south polar fluxes near September 7 and March 7, when B_0 reaches its maximum of $\pm 7^{\circ}.2$. Here it is again assumed that the polar tufts of the solar corona indicate the mean direction of the lines of force of the field and, there-

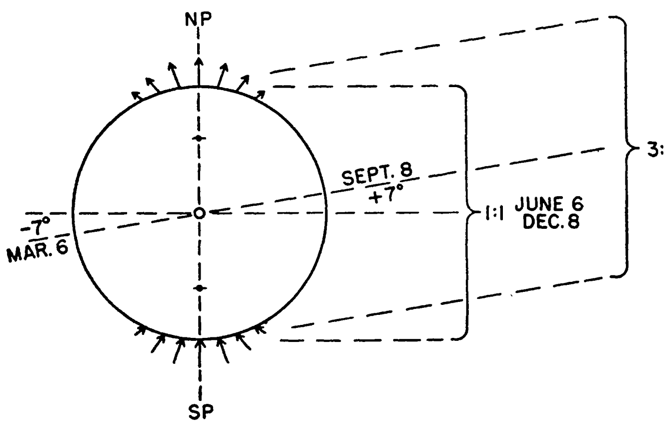

FIG. 6.—The diagram illustrates the annual variation in the magnetic-flux ratio for the north and south polar regions.

fore, following van de Hulst (1953*a*), that they appear to be tangent to lines diverging from a point on the sun's axis about 0.6 of the way out from the center. Two examples have been considered. In the first, H, the intensity of the field, is assumed to vary linearly as $\theta - 46°$, where θ is the heliocentric latitude of the point on the surface of the sun; in the second, H is assumed to vary as $(\theta - 46°)^{1/2}$. We limit our attention to two narrow uniform strips on the central meridian, one between $+46°$ and the north limb, and the other between $-46°$ and the south limb. The effective flux is $\int H \cos \gamma \cos \theta \, d\theta$ with appropriate limits. Numerical integration shows that the ratio of the magnetic fluxes near the two poles, when B_0 has its maximum value of $7^{\circ}.2$, is 3.6:1 and 3.1:1 for the two cases. Thus there is no difficulty in accounting for the magnitude and phase of the annual variation in the smoothed mean polar flux ratio.

There is no evidence from the plot of Figure 5 for a periodic variation in the north and south flux ratio of the order of 30 days, which would be expected if an appreciable obliquity prevailed between the rotational and magnetic axes of the sun. The possibility of some systematic change of the polar fields with the course of the main solar magnetic cycle is not excluded; in fact, the rather limited systematic change in average obliquity of the polar coronal streamers as a function of the phase of the solar cycle (van de Hulst 1953*a*) and the systematic migration of the "polar crown" of prominences (d'Azambuja 1948) suggest the likelihood of an observable variation in the mean effective component of the polar fields.

Quite apart from the annual variation due to the changing value of B_0, the irregular fluctuations in the effective magnetic flux in the vicinity of the heliographic poles have been so large as to defy satisfactory explanation. On a few days the effective flux (usually near the north pole) has been two to three times as strong as normal. On such days not only is the effective intensity greater, but usually also the polar field seems to extend to abnormally low heliographic latitudes. The accompanying tabulation gives the dates in

July 7	N	July 18	N	Aug. 26	NN	Sept. 22	N
9	N	19	N	27	N	Oct. 19	N
10	N	22	N	Sept. 8	N	26	N
11	N	Aug. 24	N	21	N	Nov. 8	S and N

1953 on which the polar fields (N or S) were observed to be unusually strong. Perhaps the most striking strong polar fields were observed in the north on August 26 and 27, 1953. On August 24 the effective north polar flux was greater than normal, but on August 25 it was about average. On these four days the magnetic activity on other parts of the visible hemisphere was unusually low, and it is by no means clear where the magnetic lines of force emanating from the north polar regions returned to the sun. In contrast to the foregoing, there have been other days on which both north and south polar fields were unusually weak, indeed barely detectable. Some of these days were: December 14, 21, 22, 23, 27, 30, 31, 1953; January 2, 9, 1954. Finally, for an interval of about 13 days, beginning on July 29, 1954, no evidence could be found for any field in the high southern latitudes, although the north polar field had nearly normal intensity; this is a result unprecedented in the 2 years of observation.

TABLE 1

EFFECTIVE MAGNETIC FLUX OF POLAR FIELDS

		Maximum Intensity $H \cos \gamma$ (Gauss)	Average Intensity (Gauss)	Area (Disk = 1)	F_e Effective Magnetic Flux (Maxwells)
Nov. 24 ($B_0 = +1.^\circ7$)	N	+0.9	+0.7	0.06	$+0.56\times10^{21}$
	S	−0.5	− .44	.06	-0.4×10^{21}
Aug. 27 ($B_0 = +7.^\circ1$)	N	+1.5	+ .5	.2	$+1.6\times10^{21}$
	S	−0.6	−0.3	0.0002	-0.09×10^{21}

Table 1 gives, for a "normal" record (November 24, 1953) and for an exceptional record (August 27, 1953), the measurements of the effective polar fields and of F_e, the effective magnetic flux integrated over the polar regions of the disk. These measures have been corrected for limb darkening. On August 26, the effective flux was probably even greater than on August 27, but the record was slightly marred by an irregularity in the scan; on both these days the northern "polar" field showed a most unusual extension in heliographic latitude down to 15° N.

As of October, 1954, it appears that the minimum of the sunspot cycle has been passed and that the new cycle is definitely under way. The main poloidal field of the sun has shown no reversal. If it has shown any secular change, which is doubtful, it was perhaps weaker, on the average, during the extreme minimum of the cycle. The present most reasonable course seems to be to assume (for theoretical rather than observational reasons) that the total magnetic flux of the polar fields is constant and that the apparent fluctuations result from a shifting of magnetic areas and from changes in the obliquity of the lines of force.

An estimate of the order of magnitude of the total flux of the poloidal field is of some interest for comparison with the flux of local, low-latitude fields and because it may be an essentially invariant property of the sun. For this approximate calculation we start with the typical magnetogram of November 24, 1953, on which the north polar deflections are of about average intensity and extent and for which B_0 is so small ($+1\overset{\circ}{.}7$) that it can be neglected. Allowing for limb darkening, a measure of the average magnetic intensity and of the projected area involved for each of the three traces nearest the northern limb results in a figure of 0.56×10^{21} maxwells for the integrated component of the field in the line of sight where the sun is treated as if it were a disk; i.e., $F_e = \int H \cos \gamma \, da$ on the disk. Now to convert this to total polar flux, F_t, on the spherical sun, it is necessary to assume some distribution for H. The assumption is that the magnitude of the field is $H = (H_p/44)(\theta - 46^\circ)$ and that the direction of the lines of force is as if they diverged from a point on the sun's axis 0.6 of the radius out from the center. The obliquity of the field to the line of sight is γ, where $\cos \gamma = \cos \phi \cos \psi$, and ϕ is the longitude of the point on the surface, while ψ is the projection angle in the meridional plane.

Now $F_e = \int H \cos \psi \cos \phi \, da$, for the polar cap ($\theta > 46^\circ$); and, by simple numerical methods, it is found that $H_p = 2.6$ gauss (at the pole). No special significance should be attached to this particular value of H_p, since our assumed field distribution may lead to an artificially high value at the pole. The total magnetic flux of the sun's general or poloidal field (above latitude $\pm 46^\circ$ on our assumed distribution) is

$$F_t = \int_{\theta=46}^{\theta=90} H \cos(\theta - \psi) \, d s \, ,$$

and a numerical evaluation of this integral gives 8×10^{21} maxwells. In order of magnitude, this is five times as great as the magnetic flux of an average bipolar magnetic region or of a strong unipolar magnetic region (see next section).

LOW-LATITUDE MAGNETIC EFFECTS

In the heliographic latitudes below $\pm 50^\circ$ the magnetic effects are more or less localized. No consistent evidence has been found for low-latitude zonal fields that are uniform in longitude. During the months of minimum solar activity, and especially between November, 1953, and July, 1954, the greater part, and sometimes all, of the low-latitude zones have been free of observable magnetic fields. It often appears safe to place an upper limit of 0.2 gauss over considerable areas.

But, except for the extreme minimum of the solar cycle, the low-latitude fields are often numerous, as the magnetograms show. On occasion, a small-scale pattern of weak fields ($\sim$0.5 gauss) may cover nearly the whole disk (October 29, 1954). But more characteristically there are found from one to several discrete magnetic regions of greater strength that remain identifiable from day to day. The magnetic areas range in size from very small up to a considerable fraction of a hemisphere. The field intensity typically ranges from a fraction of 1 gauss in the very large regions up to several gauss in regions of moderate size (1 or 2 minutes of arc in extent) and may, of course, be far stronger in relatively small regions, such as sunspots. The magnetic regions often change appreciably in extent and in magnetic intensity from day to day; they are transient in the sense that they disappear or lose their identity in intervals from an hour for some of the smaller, weak ones up to several months for the larger. The pattern of the magnetic fine structure, like that of the polar fields, may show significant variations in a half-hour.

Most of the prominent magnetic areas may be classed as bipolar magnetic (BM) regions, although some may have to be placed in the multipolar (MM) or complex category. The records for most of the BM regions usually suggest at least approximate equality of positive and negative magnetic flux in the respective parts. In constrast, a few very interesting areas of limited intensity we have classed as "unipolar" magnetic (UM) regions. In introducing the term "unipolar," we refer to regions which on the magnetograms show deflections almost exclusively of one polarity and which are not directly accompanied by adjacent regions of opposite polarity; in most such cases it is not at all obvious where the magnetic lines of force emanating from the UM region re-enter the sun.

BM regions.—The preceding (westerly) and following parts of typical BM regions are contiguous or nearly so and are identified by their opposite magnetic polarity; in many instances the *f* part lies at a higher latitude. Several such regions appear on the magnetograms of Figures 1–4. The magnetic polarity of the *p* and *f* parts of a BM region is the same as that regularly observed in the *p* and *f* sunspots of typical groups in the same solar cycle in the same hemisphere. According to the laws of sunspot polarity, *p* spots in the northern hemisphere have negative polarity, while *f* spots have positive polarity, in the cycle that had its maximum about 1947. The reverse is true in the southern hemisphere. A few BM regions, mostly small but with high latitude and reversed polarity characteristic of the new cycle, were observed in 1954. Sunspots, when they occur, are found within BM regions, most often while these regions are quite young. In many BM regions, however, sunspots have not been seen and possibly do not occur. The regions that involve a large total magnetic flux may persist for a long time, sometimes for many months. The most extensive BM regions may cover more than a tenth of a hemisphere; in such cases, the field is usually weak, and the limits are ill defined.

Even "old-cycle" disturbances, normally originating near the equator, may extend into high latitudes such as $\pm 50°$, sometimes merging into the polar fields. Several of the BM regions with intensities of 1–2 gauss have extended over a considerable range of latitude (30°–40° across), with a tendency for the lower-latitude part to precede toward the west. The region as a whole then shows an inclination from northeast to southwest if in the northern hemisphere. Indeed, such patterns were more common in the north in 1952 and 1953. Examples are found in the magnetograms of July 20 and October 19, 1953. Sometimes there has been a less-well-defined tendency for a symmetrical portion of the pattern to appear in the southern hemisphere, the whole magnetic area suggesting in outline a large arrowhead pointing west (July 11 and October 19, 1953). While such symmetrical patterns are rare, there sometimes seem to be coherent magnetic regions that cross the equator, as in the record of September 8, 1953. It may even appear that the principal positive and negative portions of a BM region are on the same meridian on opposite sides of the equator (February 19, 1954).

Some BM regions, even those that produce visible spots, are quite small. An example is the region that crossed the central meridian on December 26, 1953, in which small spots were observed for several days (Mount Wilson group No. 11168). The area of the BM region was about 0.002 of the disk. Other small, short-lived spots, especially of the new cycle, have arisen in very small BM regions. In a few instances, such as Mount Wilson group No. 11187, which appeared very abruptly on August 9, 1954, near 24° S. latitude, no BM field was observed on the photosphere as recently as 2 days before the appearance of the spots; the *p* and *f* spots at the outset constituted almost the whole of the BM region. The spots, however, disappeared within 5 days, leaving a more extended BM field that was carried over the west limb by rotation some days later. Usually the magnetic field persists long after the disappearance of spots and *plages*.

Some of the magnetic regions are blended, indefinite, or complex, so that it is difficult or impossible to specify their relationships. Changes from day to day may be quite pronounced, although the major BM regions, which are readily identified as "centers of activity," usually remain observable for at least several days and sometimes for several solar rotations. In parallel with the decline in the number of sunspots and *plages* near the end of the sunspot cycle, the frequency of BM regions likewise declined in the interval from the beginning of our observations until the spring of 1954. Our estimate is that the average total magnetic flux of the BM regions also decreased in this interval; but, because of the rather crude intensity calibrations of the earlier magnetograms, quantitative comparisons of total flux have not been attempted. While there is a great range in the total flux of the various regions, a typical region (1953-*Hp*) had a flux of about 1×10^{21} maxwells emanating from the *f* part and returning through the *p* part.

We have compared all our magnetograms with *Ca* II spectroheliograms taken on Mount Wilson. There appears to be virtually a one-to-one correspondence between prominent regions showing calcium flocculi on the spectroheliograms and strong BM or MM regions on the magnetograms. Examples are shown in Figures 7 and 8. Only a few of the smaller bright calcium *plages* occasionally cannot be matched by deflections on the magnetograms; this may reasonably be attributed to the limited resolution of the magnetograph. Some of the weaker magnetic regions do not produce an appreciable brightening of the *Ca* II on the spectroheliograms, but every BM region of intensity greater than about 2 gauss appears to produce a calcium *plage*.

From this it appears fairly safe to infer that calcium *plages* recorded on spectroheliograms at various observatories over the past several decades represent BM areas in which the magnetic field intensity was about 2 gauss or more. Unfortunately, the calcium spectroheliograms yield no direct information as to magnetic polarity, but it may prove possible to derive some estimate of the field intensity from the brightness of the *plages*. In some well-defined bipolar sunspot groups the *p* and *f* spots lie within corresponding *p* and *f* parts of the *plage*, and the magnetic polarity of these parts may be inferred with some degree of certainty. For spot umbras observed at Mount Wilson in the last 45 years, the polarity, area, and field intensity have been recorded; hence ϕ_s^+ and ϕ_s^-, the fluxes of the spots of positive and negative (*R* and *V*) polarity, can be estimated. If we assume that in any BM region the positive flux equals the total negative flux, we can write down the identity

$$\Phi_{BM} = \phi_s^+ + a^+\bar{H}^+ = \phi_s^- + a^-\bar{H}^-,$$

where a and $\bar{H}$ denote the area and mean field intensity of the positive and negative parts of the *plage*, apart from the spots, as indicated. This expression must be used with caution, because the BM region may extend with low field intensity far beyond the limits of the *plage*. On this same basic assumption it has been pointed out previously (Kiele 1950; Grotrian and Künzel 1950) that, because it is an observed fact that *p* spots of a group tend to be larger and to have a longer lifetime than *f* spots, in the average spot group there will be an "uncompensated" portion of the total magnetic flux. This uncompensated flux is optically ineffective in emerging from the spot, because of the darkness of the umbra, but it is fully effective in returning through the photosphere in the unspotted *f* portion of a BM region. Thus in integrated light the intermediate latitude zones of the sun should show an average magnetic field of the order of 1 gauss, with a polarity that is opposite in the northern and southern hemispheres and that reverses every $11\frac{1}{2}$ years. The assumption as to the equality of positive and negative flux in spot groups is strengthened by the magnetograms; actual measurements of the uncompensated flux of large spotted BM regions when the solar cycle is near maximum remain to be carried out.

The magnetograms have also been compared with the preliminary charts of coronal activity circulated by the High Altitude Observatory, Boulder, Colorado. These charts show the regions over which the green and red radiations are unusually bright. Again good agreement is found, in the sense that all the stronger BM regions give rise to an observable enhancement of the coronal radiations. No coronal enhancements were reported, however, over a number of the weaker BM regions. The bright, archlike patterns of the coronal radiations, best seen on eclipse photographs at times of considerable activity, provide strong evidence, if any is needed, that the vertical extent of the BM fields

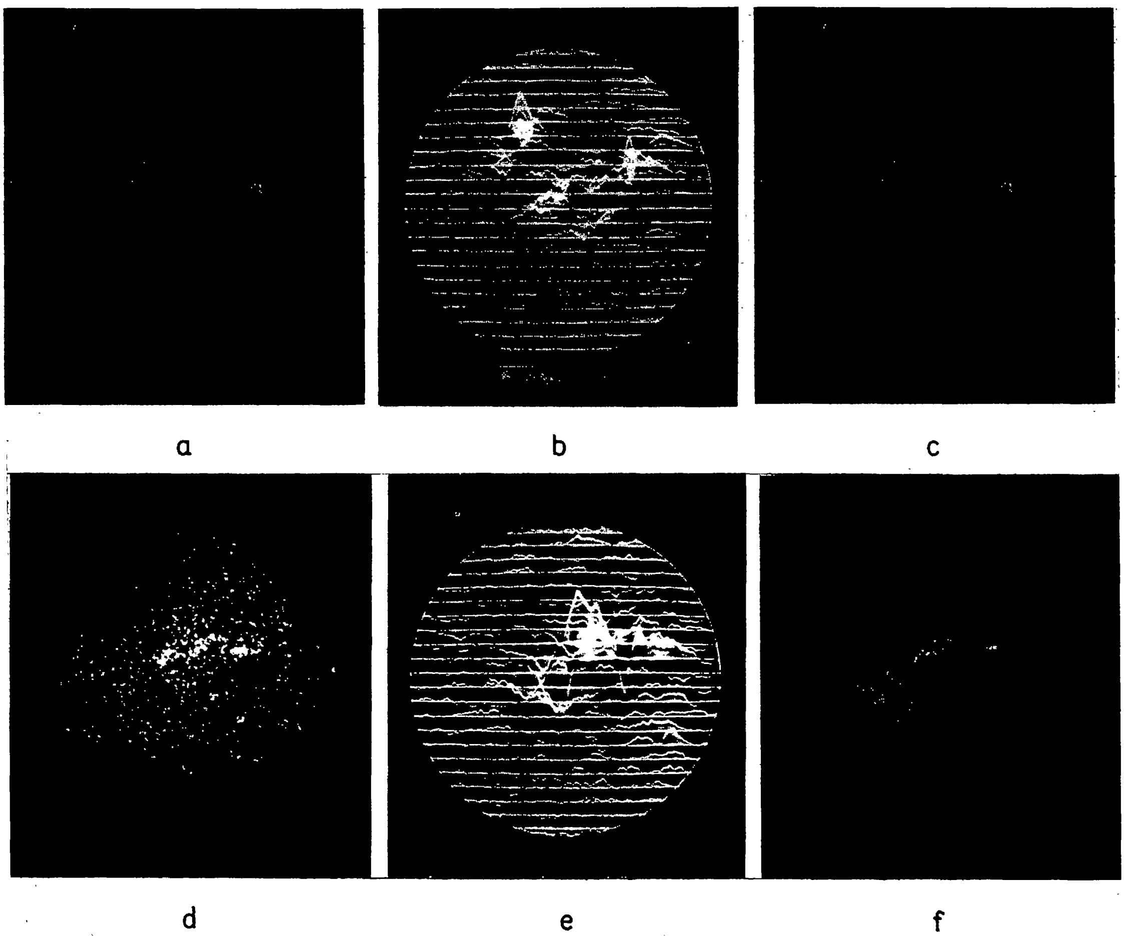

FIG. 7.—A magnetogram (*b*) is shown between (*a*) a *Ca* II and (*e*) an *Hα* spectroheliogram, all for May 26, 1953. The lower row shows a similar array for October 27, 1953. Note the *Ca* II *plages* wherever $H \gtrsim 2$ gauss. Some of the dark hydrogen filaments appear to define the locus of the tops of the arching lines of force of the BM fields.

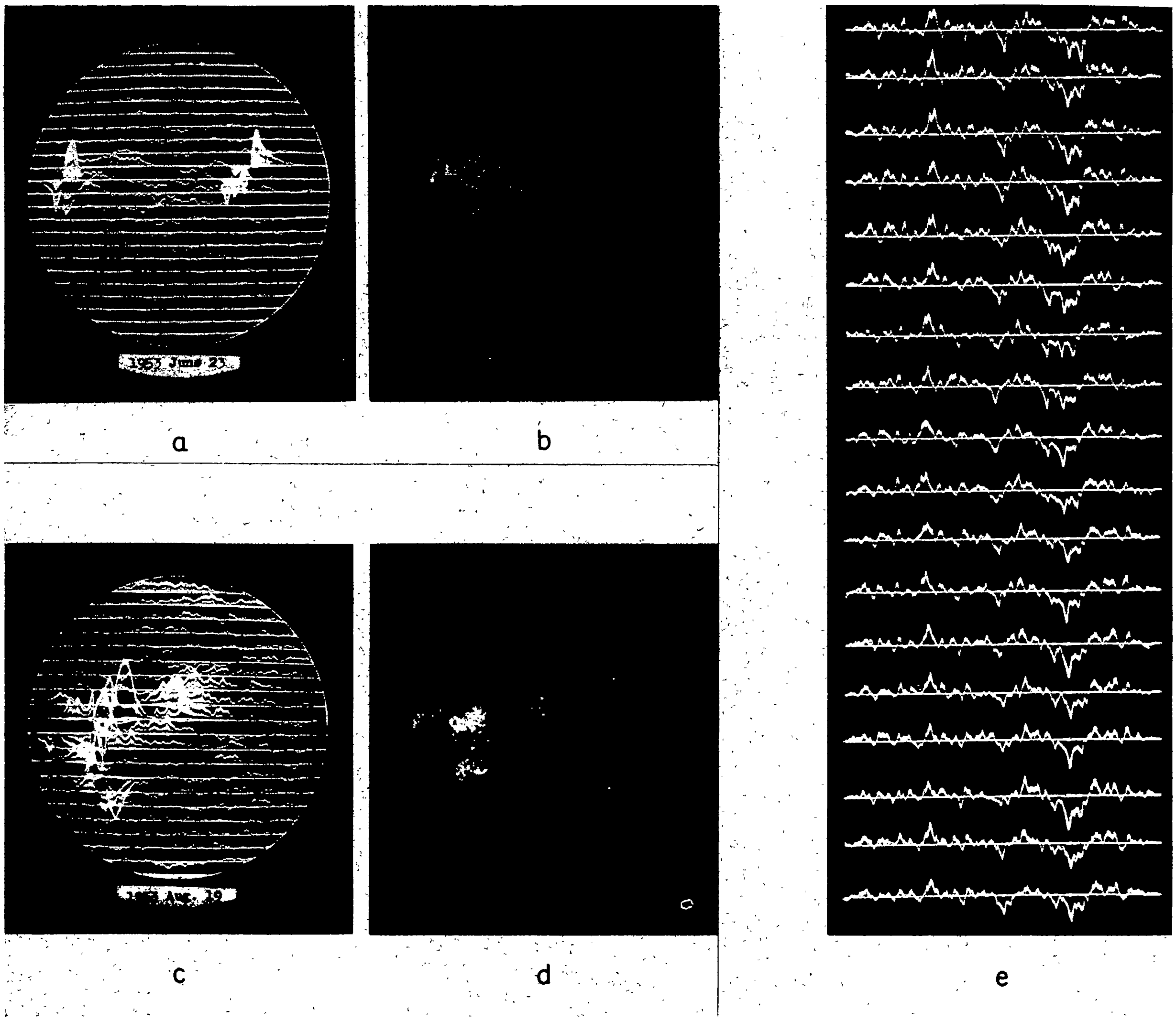

FIG. 8.—*a:* Magnetogram showing two BM regions and weak fields on June 23, 1953. *b:* *Hα* spectroheliogram of the same date. The bright flocculi lie in the regions of strongest field, while the dark filaments seem to separate the areas of opposite magnetic polarity. *c:* A prominent UM region appears near the center of the disk on August 19, 1953; the connection, if any, with the two BM regions farther west is not clear. *d:* The corresponding *Ca* II spectroheliogram shows intense *plages* in the BM regions where $H \gtrsim 2$ gauss, but not in the UM region. *e:* Repeated diametral traces made with careful guiding at 10-minute intervals on June 7, 1954. The largest deflections correspond to about 2 gauss. Note the changes of detail within 20–30 minutes.

into the corona is at least of the same order as their horizontal extent, and often much greater.

UM regions.—Unipolar magnetic regions occur in the same zones of latitude as BM regions, but they are relatively rare. They are of low magnetic intensity and often cover a rather large area with ill-defined limits. They usually bear no obvious relationship to other features of the magnetic pattern. The lines of force that emanate from UM regions presumably return to the sun diffusely in areas that are far from the center of the disk. The field intensity of UM regions ranges from a few tenths of a gauss up to perhaps 3 gauss. The best example of such a region was recognizable for at least six solar rotations and is best shown on the records of July 22 and August 19, 1953. Measurements on the magnetograms yield the data on this UM region shown in Table 2.

Figure 8, *c*, shows the UM region of positive polarity centered nearly on the central meridian at about 15° N. latitude on August 19, 1953, with *d* a Mount Wilson spectroheliogram in the light of *Ca* II on the same date. Two BM regions, some 35° west of the UM region and on opposite sides of the equator, are related to the usual bright *Ca* II *plages*, but there is scarcely a trace of brightening on the spectroheliogram at the location of the UM region. Furthermore, the preliminary records of the coronagraph observers at the High Altitude Observatory indicate no coronal brightening over the UM region.

TABLE 2

1953	Max. Intensity (Gauss)	Average Intensity (Gauss)	Area (Disk = 1)	Total Flux (10^{21} Maxwells)
July 22.........	3.2	+0.7	0.16	+1.8
Aug. 19.........	2.0	+ .43	.15	+1.0
Sept. 15.........	1.5	+0.4	0.13	+0.8

The indications are that the UM regions revealed by the magnetograph constitute a kind of solar phenomenon not directly observable by other means. It has been noticed that the most prominent series of 27-day sequential terrestrial magnetic storms of 1953 showed its successive onsets about 2–3 days after central meridian passage (c.m.p.) of the UM region referred to earlier, which was by far the most conspicuous such region of the year. This correlation is illustrated in the diagram of Figure 9, where each horizontal row represents a sequence of 27 days, or one solar rotation. It will be recalled that magnetic storms are of two general classes: sporadic, which can be related to solar flares; and 27-day-recurrent, which have been attributed to hypothetical "M" regions on the sun (Bartels 1932; Allen 1944). Only the latter class is of interest here. The "M" regions are believed to be the sources of neutral but ionized corpuscular streams, giving rise to the terrestrial magnetic storms of the recurrent type, and they have been suggested as the roots for far-reaching coronal streamers.

We wish to propose that the newly observed UM regions may be identified with the heretofore hypothetical "M" regions. This suggestion rests mainly on the evidence of Figure 9, where the best UM sequence and the best magnetic storm sequence appear related; the delay of 2 days or more between c.m.p. of the UM region and the onset of the storm is about what had been predicted by Allen on the basis of particle speeds. It is also plausible that if corpuscular streams are to escape from the sun at all, they should do so along a coherent, nearly radial, bundle of magnetic lines of force such as one visualizes as arising from a UM region. Additional correlations of UM regions and magnetic storm sequences are much to be desired to make the identification more secure, but there have been no observations of outstanding UM regions in 1954 to date (and no outstanding storm sequences). It has been remarked that "M" regions (and also low-latitude coronal

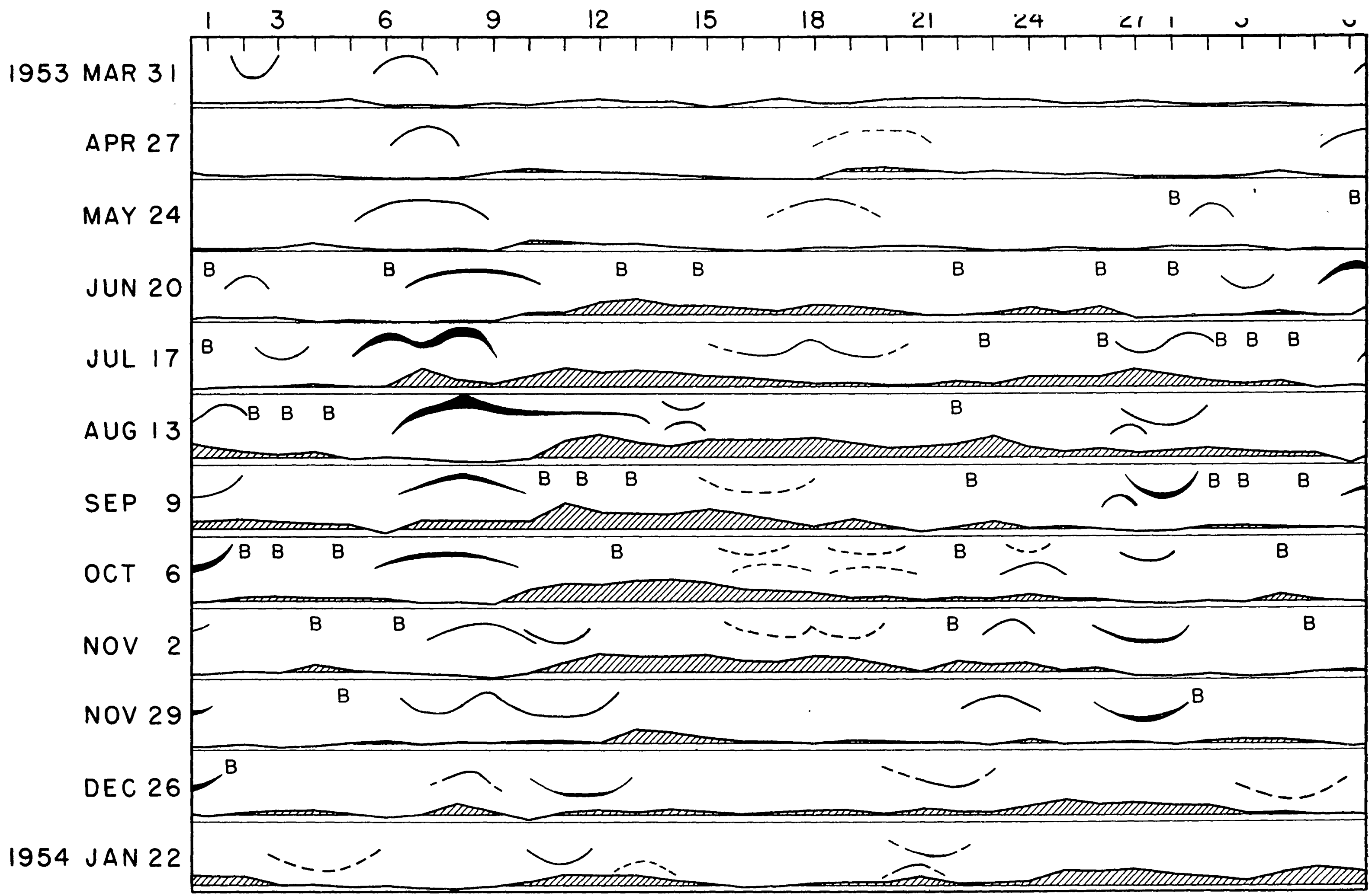

FIG. 9.—The diagram presents evidence tending to relate terrestrial magnetic storms of the sequential type to UM regions on the sun. Each row represents one solar rotation of 27 days (plus 6 repeated days). The date of the first day of each row is given at the left. For each day the K sum (geomagnetic planetary index) is plotted, and under the connecting curve all areas for $K > 10$ have been shaded. UM regions have been indicated, according to date of c.m.p., by **U**-shaped curves, convex upward or downward according as the magnetic polarity is positive or negative. The attempt has been made to suggest the extent of the UM regions and their relative flux. C.m.p. of the best UM region of 1953 was followed, on several successive rotations, by the onset of a 27-day sequential magnetic disturbance on the earth. A delay of 1-4 days usually occurred. Dates of c.m.p. of the stronger BM regions are indicated by the letter B, but these are thought not to be directly relevant.

streamers) are most numerous in the declining years of the sunspot cycle and show their greatest development 1 to 2 years before sunspot minimum. Hence 1953 was perhaps the last year in which prominent "M" or UM regions would be expected until after the next spot maximum.

It has been reported that the best 27-day sequential magnetic storms, with their inferred "M" regions, tend to occur seasonally when B_0, the heliocentric latitude of the earth, is near its maximum of $\pm 7°$ (Chapman and Bartels 1940). This is also in agreement with the proposed identification, for the UM regions are probably centered in the same latitude zones as BM regions—therefore, seldom below 6°. The probability that some UM regions will pass near the center of the apparent disk is therefore greatest in early March and September in the declining years of the sunspot cycle (and if they are remnants of BM regions, they will be more numerous in these years). If the corpuscular streams arising in UM regions emerge nearly radially or with a longitudinal lag in rotation, they will be more likely to interfere with the earth in these seasons.

It is worth pointing out that well-defined UM regions should be rather readily identifiable on magnetograms some 3 days before c.m.p. Since magnetic storms of the recurrent type commence 2–4 days after c.m.p., if our suggestion is correct, the possibility exists of strengthening the predictions of terrestrial storms and their associated effects if the solar magnetic observations are continued on a routine basis.

An effort was made to find, on *Hα* spectroheliograms, some evidence of the occurrence of UM regions. Such spectroheliograms show, in general, a small-scale random pattern of light and dark chromospheric filaments. In BM regions where the field has an intensity of a few gauss (and possibly also in the best UM region) the pattern of the fine structure in the *Hα* spectroheliograms assumes a larger-scale coherence. Presumably the direction and coherence of the filamentary structure are determined by the magnetic field. But this effect on the pattern of the chromospheric filaments, at least for the weaker fields, is discernible only on occasional spectroheliograms of exceptional quality. Were it not for this limitation, one could hope to identify UM regions of past decades by examining existing *Hα* spectroheliograms in a search for the larger-scale coherent patterns, rejecting all those that coincide in location with *Ca* II *plages* and which are therefore presumably BM regions. An examination of a number of the older Mount Wilson *Hα* spectroheliograms, preselected by picking dates preceding prominent sequential-type magnetic storms, was unsuccessful because the filamentary structure was adequately shown on so few of the plates.

Hydrogen flocculi and prominences.—Hydrogen spectroheliograms, along with magnetograms for the same dates, are shown in Figures 7 and 8. These and several other comparative observations show that bright hydrogen flocculi are found in the stronger portions of all prominent BM regions, but these bright flocculi are not so extensive as are the corresponding *Ca* II *plages;* apparently they are less sensitive as indicators of weak magnetic fields. A more sensitive indication is furnished by the alignment of the fine filamentary *Hα* structure into an extended coherent pattern.

Prominences, appearing as dark hydrogen filaments, are seen on the spectroheliograms. The filaments shown are rather stable. A comparison with the magnetograms brings out some points of interest in regard to the position of the filaments. Some of them are situated on or near the borders of the magnetic regions, partly encircling them (perhaps preferentially on the high-latitude side). Other filaments seem to lie along a line dividing the BM region into two parts of opposite polarity. In the latter cases it would appear that the absorbing hydrogen has accumulated along the locus of the tops of the arching lines of force of the magnetic field. The photospheric fields in the vicinity of the filaments are of the order of 1 gauss.

The extensive observations of hydrogen filaments by M. and L. d'Azambuja (1948) show that the low-latitude filament zones migrate with the sunspot zones, remaining about 10° poleward of them; this is just what would be expected from our observation that filaments tend to delimit BM regions on the high-latitude side. The slow poleward migration of filaments (about 1° per rotation) observed by d'Azambuja may result from a gradual expansion of BM regions or perhaps in part from their proper motions. It has also been reported that long-lived prominences, in their terminal phases, drift poleward to form a "polar crown" at latitudes above 40°. This activity varies with the $11\frac{1}{2}$-year cycle. The polar crown nearly reaches the poles at sunspot maximum and thereafter disappears, to recur in about 3 years at latitudes of 40°–50°. There is a temporary decrease at spot minimum. By inference, one expects that a continuation of magnetic measurements throughout the solar cycle may disclose significant changes in the high-latitude magnetic fields of the sun. In fact, we could speculate at this stage that the polar magnetic field is the result of poleward migration of the *f* portions of disintegrating BM regions in the first few years of each sunspot cycle. If this were true, the main poloidal field should reverse its polarity every $11\frac{1}{2}$ years, but out of phase with the frequency-curve for sunspots. On this theory the residual *p* portions of BM regions should either be neutralized by merging of low-latitude fields of the northern and southern hemispheres, or there should be evidences of a general quadrupolar field. The intensity of the average low-latitude components of the quadrupolar field should be of the order of 0.3 gauss, which could hardly have escaped observation.

History of a BM region.—An attempt was made to trace the development of a prominent magnetic region from its outbreak in March, 1953, until all trace of it was lost in January, 1954. In its earlier stages this region was designated 1953-*Hp* on the charts of the High Altitude Observatory. Measurements of the area and of the magnetic flux involved were made on the magnetograms available on or near the dates of successive c.m.p.'s. The results are plotted in Figure 10. No great precision can be claimed for the measurements, but the broad features are significant.

The BM region was centered at about 10° N. Activity apparently broke out on the far side of the sun shortly before an active prominence was observed (on spectroheliograms) coming around the east limb on March 25. Two days later a *plage* and a small spot group (No. 11098) came into view. No coronal maximum was reported at the east limb at this time, but enhanced emission was observed at subsequent limb passages through August. In other BM regions it has been observed that an interval of 1 to a few days is typical between the first observation of a magnetic field and the appearance of spots. This general region showed much more activity and larger spots on the next rotation. A flare was reported on April 24. It is possible that a new and stronger disturbance broke out after the first passage while the region was out of view, for on the second passage a very conspicuous spot group (11107) was located about 15° farther east than would be expected for a return of 11098.

Because of poor weather and alterations to the equipment, no magnetograms were obtained until the third appearance of 1953-*Hp* near the end of May. However, for the first two appearances, lower limits to the magnetic flux of the region and to its area were estimated from the Mount Wilson sunspot tracings and spot field intensities, as well as from the *Ca* II spectroheliograms. The BM region probably extended beyond the limits of the *plage*. The visual measurement of the central field intensity of the principal (*p*) spot in 11107 was −3200 gauss (Hickox), and the flux of the umbra alone was estimated to be about 1.8×10^{21} maxwells. On the third and fourth appearances, small spots, practically all of *p* (negative) polarity, were observed (11118 and 11126). The BM field of spot group 11132 (10° S.) interfered somewhat with the measurement of the region in July. No correction to the total flux for the effects of small spots was attempted after the c.m.p. of April 28. No spots were observed in the region after June 22 (fourth appearance). The *Ca* II *plage* gradually faded but was observable through the c.m.p. of August.

After a high degree of activity in the first 2 months of its existence, there seems to have been a marked decrease in the total magnetic flux of the region, possibly as a result of subsidence of associated material; this was followed by a relatively stable phase, during which the region gradually expanded, with an end to coronal and *plage* activity and a decrease in maximum field intensity. The total flux of the (*p*) part of the BM region remained reasonably constant until the middle of January, 1954, after which it was lost in the random background of weak fields. No clear answer can be given as to the fate of the (*f*) part of the region. Presumably, it expanded (or migrated) more rapidly as the BM region disintegrated. The effective result is that the BM region degenerated into a UM region. As a UM region it passed considerably north of the center of the sun's disk, and for this reason may not have produced appreciable "M" region effects.

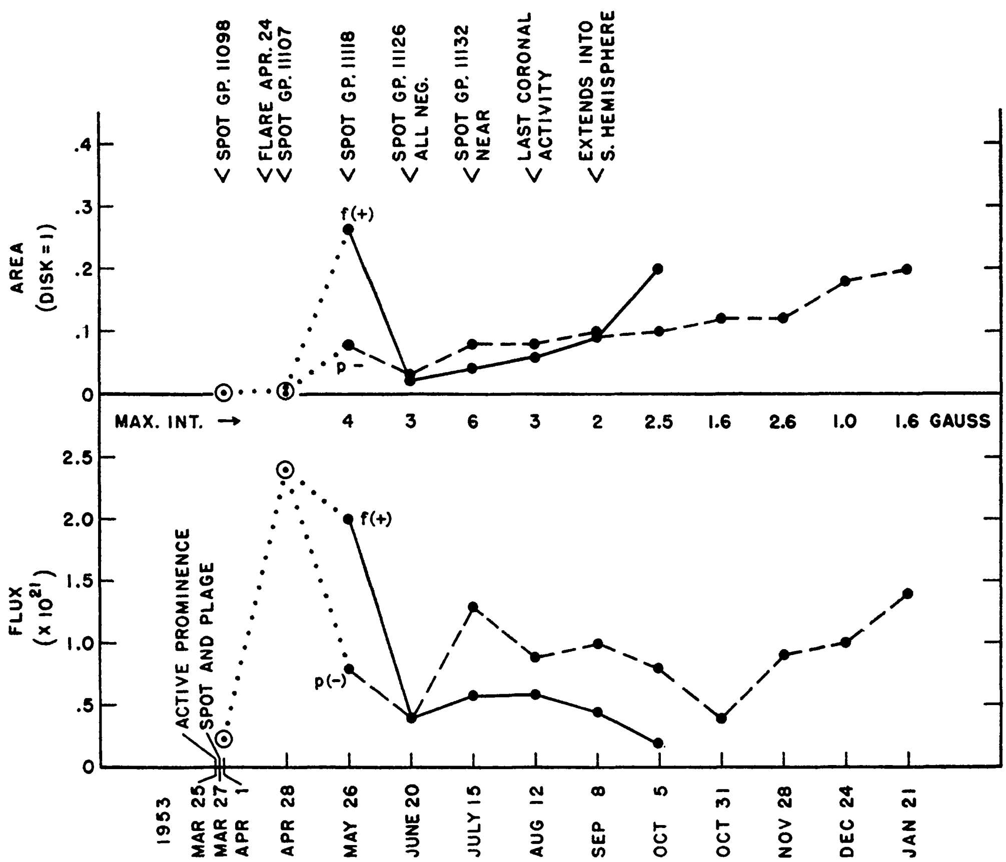

FIG. 10.—Development of the magnetic region associated with the center of activity 1953-Hp through 12 solar rotations. Measures of the area of the preceding and following parts of the BM region are plotted in the upper part of the diagram; below are estimates of the magnetic flux of the two polarities. The magnetic region was observable long after most outward signs of activity had subsided; in the final stages, only the preceding part, of negative polarity, could be identified.

While 53-*Hp* persisted as a recognizable magnetic region for the better part of a year, it has been observed that small BM regions having a flux only about one-tenth as great may appear, produce small spots, and then disappear rapidly and completely in a matter of days.

Rate of change.—A comparison of magnetograms shows that very appreciable alterations in the magnetic pattern may take place in intervals of a day; this is particularly true for the early stages of BM regions. Some of the daily changes are only apparent, because the path of the scanning slit with respect to the magnetic features is variable. But real physical variations, involving changes in the total magnetic flux in the loops that break through the surface and also changes in the mean angle between the lines of force and the line of sight are obviously present. It would be of interest to establish characteristic time constants for the magnetic fluctuations as a function of the size of the surface elements involved. A preliminary attempt in this direction is shown in Figure 8, *e*, where repeated traces, at 10-minute intervals, were made along the same diameter of the sun's image. The image was carefully guided, so that the same strip was repeated rather exactly, and the speed of scanning was about one-third that ordinarily used, so that finer detail of the magnetic pattern is shown. The slit had its usual length of 15 mm. In this special record, made on June 7, 1954, the largest deflections indicate a field of about 2 gauss. The principal features of the pattern are identifiable on all traces, but the details change within intervals of a few minutes. Note, for example, the variations in the relatively wide region showing the largest negative peaks. On the seventh trace, this region has three peaks, nearly equal; on the twelfth trace, it has only one major peak. From this and similar records, all indications are that in regions where an outstanding weak magnetic field exists, fluctuations of the order of 0.5 gauss may occur in a few minutes; this result applies, of course, to the average field over an area of the order of 5×10^8 square km. Such variations in the effective field are attributable in part to turbulence of the photosphere, which may produce a fluctuating pattern of widely separated concentrations of the magnetic lines of force, in which the field is much stronger than the mean value.

As was pointed out earlier, an upper limit of 0.2 gauss can often be placed on the effective magnetic field over very large areas of the quiet sun. This is of interest in connection with the possible fields of individual granules, considered apart from more deeply rooted coherent fields. If we assume that the granules average 1 second of arc in diameter, there may be about seventy of them along the length of the slit; and, if we assume further that each granule has a coherent field H_g and that, because of turbulence, they are oriented at random, we see that an upper limit on H_g is roughly 2 gauss.

CORPUSCULAR EMISSION

A number of the known facts concerning "centers of activity," prominences, localized solar radio emission, "M" regions, and other solar phenomena can be synthesized with the observations of weak solar magnetic fields on the hypothesis that electrically neutral streams of ions (mostly protons) and electrons are more or less continually ejected from the solar surface in all turbulent regions having a coherent magnetic field of average intensity $\frac{1}{2}$ gauss or more. Because of the high degree of ionization, such streams, guided by the lines of force, are essentially invisible except in so far as they excite the weak radiations of the coronal rays, fans, and arches.

The idea of outgoing corpuscular streams is not new, but we believe that the magnetic observations place it on a firmer footing. Chapman and Ferraro's (1932) theory that neutral but ionized streams of particles from the sun are responsible for terrestrial magnetic and ionospheric effects has already received good observational support. There is evidence that protons travel outward from the sun, with mean velocities of some hundreds of kilometers per second (Vegard 1939; Gartlein 1950; Meinel 1950). These observations relate to sporadic phenomena, but similar streams are supposed to proceed from "M" regions, which we suggest are identical with the newly observed UM regions.

The way in which the particles are accelerated is unknown, but hydromagnetic fluctuations in the photosphere and chromosphere, involving turbulence in the presence of a deeply rooted magnetic field, must be given strong consideration. The hope is that a way may be found in which a fraction of the energy of massive turbulence may be channeled, through the agency of local magnetic field concentrations, into the outward energy of motion of ionized streams of low density but high velocity. Such a model may be based on the observations of transient chromospheric jets or spicules, which have been summarized by van de Hulst (1953*b*).

In the layers considered, hydrogen is largely neutral, but the conductivity is sufficient that in a large element of volume the nearly vertical magnetic lines of force remain identified with the material. Owing to random motions, partly horizontal, with velocities of the order of 2–3 km/sec, occasional elements of volume will be squeezed from all sides, so that the lines of force become concentrated into concentric cylindrical tubes. The material, being free to flow along the tubes of force, escapes upward, so that a long, thin cylinder results. The upward velocity of flow at this stage, due to continuity, may be of the order of 10 or more km/sec. If the process continues until the magnetic pressure in the cylinder (which varies as the inverse fourth power of the radius) is significant in destroying the momentum of the inward-pressing material, the field H may temporarily reach values of the order of 600 gauss. This results from equating the magnetic pressure, $H^2/8\pi$, to ρv^2, where ρ, the density in the photosphere, is taken to be 4×10^{-7} gm/cm^3. After 100 seconds, the column of high field intensity will have a radius, at its base, of the order of 10 km. There has resulted a pronounced constriction in the concentric tubes of force; this generates a specialized form of hydromagnetic wave which will travel upward with a velocity $a = H/\sqrt{(4\pi\rho)}$, which is to be added to the initial jet velocity. Owing to the rapid decrease of density with height, the velocity of the constrictions will increase upward, provided that H does not decrease too rapidly and provided that the wave is not dissipated by secondary (heating) effects. If H were to retain its value of 600 gauss, the traveling-wave velocity of the constrictions would rapidly increase from 2.5 km/sec near the photosphere to 2500 km/sec at a height (somewhat above 6000 km) where the density has decreased by a factor of 10^6. The actual velocity must be less because of the direct dependence of a on H, but the nearly constant width of spicules and many coronal streamers suggests that the decrease of H with height is not so rapid as to cancel the effect of decreasing density. On this model, then, there is some expectation that wave velocities of a few hundred km/sec might be attained in the high chromosphere or inner corona. Finally, we suppose that relatively small tenuous clouds of ions and electrons are squeezed ahead of the constrictions and are thus accelerated upward with the traveling waves.

In any such process as the foregoing, the lines or tubes of force above the photosphere would be dominant in determining the disposition of the material, except perhaps for particles of very high energy. Over a BM region, particles accelerated upward from the extended areas of opposite polarity would be guided by the arching lines of force until they collided and condensed over the region at a considerable height, thus forming a prominence. The material in a prominence becomes visible by reverting partly to the neutral condition, and it begins a possibly lengthy but precarious existence under the influence of magnetic and gravitational forces. Eventually, much of the material slides back down the magnetic lines of force, or, in part, it may be thrown outward by expansion of the arching BM field.

The collision of gas clouds at relative velocities of several hundred kilometers per second has been observed in other cosmic sources to be a necessary condition for the generation of radio-frequency radiation (Baade and Minkowski 1954; Minkowski and Greenstein 1954). On this basis one could expect the fields over BM regions on the sun, but not UM regions, would be outstanding as local sources of radio noise. Through the great kindness of Dr. J. L. Pawsey and Mr. J. A. Warburton, of the Commonwealth Scientific and Industrial Research Organization, Sydney, Australia, we have been permitted to examine, before publication, records of radio observations of the sun made with a Christiansen interferometer having a resolution of about 3′ in the east-west direction. A preliminary comparison with magnetograms of 1953 shows that, in fact, there is good correspondence between "bright" radio regions and BM regions. UM regions, however, were not identifiable as radio sources on the available records. Corpuscular streams accelerated outward from UM regions would be expected to proceed more or less radially for an indefinite distance, depending upon the interaction of weak and rather irregular magnetic fields at some distance from the sun; since there is little chance of their colliding with other ion clouds before they have become very diffuse, they they are not generators of strong radio noise.

The north and south polar regions of the sun, in which the lines of force of the general field arise, may be regarded as UM regions of a special class. They are quite extensive and (at least relatively) permanent. Coronal plumes or tufts, as well as spicules, are certainly associated with the polar regions. All this suggests that if the low-latitude UM regions are, in fact, sources of corpuscular streams, then the sun's polar regions may well be even more copious sources. The lines of force of the general field presumably loop outward to great distances in the solar system and must undergo severe distortion by moving ionized clouds. These lines of force will, however, guide diffuse corpuscular streams ejected from the polar regions to the general vicinity of the equatorial plane; because of magnetic coupling, such outgoing streams will carry a share of angular momentum that is large in proportion to their mass. Since the total magnetic flux of the polar regions is probably several times as great as that or ordinary UM regions, angular momentum, as well as mass, will be carried away preferentially from the high heliographic latitudes.

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