The measurements of the interplanetary magnetic field taken with the Mariners 2, 4, and 5, and OGO 5 cover several parts of the interval from September 1962 to the present and several paths through the region between 0.7 and 1.5 AU and between ±7.3° in solar equatorial latitude. From an analysis of these measurements we find evidence for a distinct dominant polarity effect in the magnetic field. Specifically, the dominant polarity of the field was inward (toward the sun) at heliographic latitudes above the solar equatorial plane and outward (away from the sun) at latitudes below this plane. Magnetographs of the polar regions of the sun indicate that the dipolar component of the sun's field has been inward over the northern hemisphere and outward over the southern hemisphere since the last maximum in solar activity, which occurred in 1958. Our results suggest that over most of a solar cycle, the dominant polarity of the interplanetary field in either the northern or southern hemisphere of interplanetary space is just that of the dipolar component of the sun's field in the same hemisphere.

INTRODUCTION

Spacecraft observations of the interplanetary magnetic field now cover rather wide ranges of time and space. These include measurements taken above and below the solar equatorial plane, at heliocentric distances ranging from that of Venus (0.7 AU) to that of Mars (1.5 AU) and at several phases of a solar cycle.

In studying these observations we have found evidence for a latitude-dependent dominant polarity in the interplanetary magnetic field. This dominant polarity effect may be stated as follows: Over any solar-rotation (SR) period, the dominant polarity of the field recorded at a point in space has a strong tendency to be the same as that of the dipolar component of the sun's field. The term 'dipolar component' is used herein to refer to the weak dipolar background field of the sun as described by Babcock [1961].

More specifically, magnetograms of the sun indicate that the dipolar component of the sun's field, seen most clearly in the polar regions, is at present like that of the earth, with field lines leaving (positive) over the southern hemisphere and entering (negative) over the northern hemisphere of the sun. This has been the configuration of the solar poloidal (dipolar) field since the solar maximum of 1958 [Livingston, 1966].

According to our analysis of the previously mentioned in situ field measurements, the dominant polarity of the interplanetary field was usually positive at heliographic latitudes below the solar equatorial plane and negative for spacecraft observations at heliographic latitudes above this plane during the interval, 1962–1968, covered by the data.

In the following sections we will first describe our analysis and the results. We will then review previously reported measurements of the polarity of the interplanetary field, all of which appear to be consistent with those analyzed here. Finally, we will consider the likely significance of this dominant polarity effect.
TABLE 1. Latitude of the Earth during the Year in the Solar Equatorial System

<table>
<thead>
<tr>
<th>Date</th>
<th>Latitude of the Earth, deg</th>
<th>Date</th>
<th>Latitude of the Earth in Solar Equatorial System, deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec. 3</td>
<td>0.6</td>
<td>June 4</td>
<td>-0.3</td>
</tr>
<tr>
<td>Jan. 3</td>
<td>-3.3</td>
<td>July 3</td>
<td>3.1</td>
</tr>
<tr>
<td>Feb. 2</td>
<td>-6.1</td>
<td>Aug. 3</td>
<td>6.0</td>
</tr>
<tr>
<td>March 5</td>
<td>-7.3</td>
<td>Sept. 3</td>
<td>7.2</td>
</tr>
<tr>
<td>April 5</td>
<td>-6.3</td>
<td>Oct. 2</td>
<td>6.7</td>
</tr>
<tr>
<td>May 5</td>
<td>-3.7</td>
<td>Nov. 2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

ANALYSIS OF THE DATA

We report here on one phase of an analysis of the records from the magnetometers carried on board Mariners 2, 4, and 5, and OGO 5. The primary result of this phase of our work is the statistical evidence that the dominant polarity of the interplanetary magnetic field was a function of heliographic latitude, having been inward (toward the sun) in the northern latitudes (0-7.3°N) and outward in the southern latitudes (0-7.3°S).

For the purposes of this study, the measured magnetic field \( B \) was expressed in terms of its three vector components, \( B_r \), \( B_\theta \), and \( B_\phi \) in the conventional spherical polar coordinate system with the polar axis coincident with the sun's axis of rotation. Thus, \( B = rB_r + \theta B_\theta + \phi B_\phi \), where \( r, \phi, \) and \( \theta \) are unit vectors in the coordinate directions, i.e., \( r \) is radially outward, \( \phi \) is in the direction of the motion of a point on the rotating sun, and \( \theta \) completes the right-handed system. Thus, the colatitude \( \theta \) is just \( (\pi/2) - \beta \), where \( \beta \) is the latitude.

The latitude of the earth and the latitude ranges of the Mariner and OGO 5 spacecraft are listed in Tables 1 and 2, respectively. Also listed in Table 2 are estimated latitude ranges of IMP's 1, 2, and 3, Pioneer 6, and Explorers 33 and 35, to be discussed in the next section.

Figure 1 shows the polarity patterns for eight of the ten records studied. The polarity pattern from the Mariner 5 flight is to be published shortly [Davis et al., 1968]. From the records of the three Mariners and OGO 5, 27-day totals, computed every three days, were made of the number of data points \( (NBr+) \) of the field's radial component, \( B_r \), that were positive (+polarity) and for those \( (NBr-) \) that were negative (−polarity). The tangential component, \( B_\theta \), usually had the sign opposite to \( B_r \), as required by the spiral-field model. Only one solar rotation period is covered by available OGO 5 data. In Figure 2 the day and spacecraft latitude, \( \beta \), of each plotted point are those at the middle of each 27-day period.

Adding together the number of points for the positive polarity and the number of points for the negative polarity gives the total number of points available for each overlapping 27-day period in Figure 2. Where the total number of points is less than the maximum, there were gaps in the data. These data gaps are responsible for some of the minima in the difference between the positive and negative polarity curves.

The relative heights of the positive and negative polarity peaks in the 27-day distributions of \( B_r \) and \( B_\theta \), derived from the Mariner 2, Mariner 4, Mariner 5, and OGO 5 data are consistent with Figures 1 and 2. Sample histograms, all for 27-day periods, are shown here (Figures 3–5), and others, along with polarity distributions for each solar rotation period, appear in the reports on other studies of the data from these same spacecraft (see references).

The Mariner 2 (7° latitude) data [Coleman, 1966] exhibited 57% negative polarity (Figure 3) early in the flight and a reduction to about 50% near the beginning of the nine-day gap, which began about November 1, 1962. (Because of the length of this gap, the section of the Mariner 2 record used here ends on this date.) The fact that most of the smaller gaps occurred in the negative sector of the data probably accounts for the decreasing tendency of the difference between the (+) and (−) polarity curves. In other words, there were a number of gaps of smaller length in the Mariner 2
record distributed in a manner that biased the
distribution of \( B_r \) toward \( B_r > 0 \). This con-
clusion is based upon the fact that \( B \) was less
than zero on either side of most of the gaps.
Thus, if the dominant polarity was the same
in any gap as it was on either side of the gap,
the actual distributions would be shifted toward
\( B_r < 0 \).

When the gaps were filled in by giving all
the 293 points possible per 3-hour interval to
the polarity that dominated during the time
that data were available for that three-hour
interval, the difference between the (+) and
(−) curves increased appreciably (Figure 2).
The minimum percentage of negative polarity
was then 53\% (the maximum was 60\%) just
before the analysis ended at the large 9-day
data gap.

There were gaps in the Mariner 4 and
Mariner 5 data, also. In these cases, the gaps
were fewer and more randomly distributed so
that the dominant polarity was easily estab-
lished.

The flight of Mariner 4 was just after the
minimum of the solar activity cycle. From
Table 2 and Figures 1 and 2, it is seen that the
dominant polarity recorded during the Mariner
4 flight is positive (up to 70\%) at southern lati-
tudes and that the dominant polarity changes
to negative (up to 72\%) after the spacecraft
crosses into northern latitudes. Data gaps,
probably mostly in the positive polarity sec-
tors, caused fluctuations in the number of
points. The component along the spiral-field di-
rection, \( B_\phi \), as measured with the Mariner 4
magnetometer, is given for 3-hour intervals for
SR 1797-1808 (Bartels’ solar rotations) in Cole-
man et al. [1967].

For a region with very little missing data,
Figure 4 shows a histogram of \( B_\phi \) and \( B \). The
 corresponding latitude is −6.7°. The reduced
dominance of the positive polarity between
Days 132 and 192 will be mentioned in the Dis-
cussion section. The relative number of Zurich
observed sunspots gradually increased from ten
in November 1964 to twenty in October 1965
[Ionospheric Data, 1968].

Mariner 5 started at northern latitudes. The
dominant polarity was negative with the occur-
rence of this polarity as high as 80\% (Figure
5). The percentage negative polarity decreased
to 47\% at latitudes between 0 to −2°. There
is a large data gap from Day 266 through
Day 273, probably in the negative sector.

From the Mariner 5 data, Davis et al. [1968]
have determined \( B_\phi \), the field component in
the spiral-field direction, for SR’s 1832-1837.
Besides the very dominant negative sector,
there is a small positive polarity sector near
the beginning of SR 1832 and a small positive

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Distance from Sun, AU</th>
<th>Launch Date</th>
<th>Latitude Range of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mariner 2</td>
<td>0.85–1.0</td>
<td>Aug. 27, 1962</td>
<td>7.3° up to 7.8°, then down to 6°</td>
</tr>
<tr>
<td>IMP 1</td>
<td>1.0</td>
<td>Nov. 27, 1963</td>
<td>0° down to −5°</td>
</tr>
<tr>
<td>IMP 2</td>
<td>1.0</td>
<td>Oct. 4, 1964</td>
<td>6° down to 4°</td>
</tr>
<tr>
<td>Mariner 4</td>
<td>1.0–1.5</td>
<td>Nov. 28, 1964</td>
<td>0° down to −7°, then up to 0° (8/14/65)</td>
</tr>
<tr>
<td>IMP 3</td>
<td>1.0</td>
<td>May 29, 1965</td>
<td>0° up to 7° (9/3/65), down to 0° (12/3/65),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>then down to −5°</td>
</tr>
<tr>
<td>Pioneer 6</td>
<td>0.83–1.00</td>
<td>Dec. 16, 1965</td>
<td>−1° down to −7°, then up to 0° (early May</td>
</tr>
<tr>
<td>Explorer 33</td>
<td>1.0</td>
<td>July 1, 1966</td>
<td>1966), up to 7°, down to 3°</td>
</tr>
<tr>
<td>Mariner 5</td>
<td>0.68–1.00</td>
<td>June 14, 1967</td>
<td>3° up to 7°, down to 0°, down to −7°, and</td>
</tr>
<tr>
<td>Explorer 35</td>
<td>1.0</td>
<td>July 19, 1967</td>
<td>so on. Data shown in Figure 1 start in</td>
</tr>
<tr>
<td>OGO 5</td>
<td>1.0</td>
<td>March 4, 1968</td>
<td>October 1966, at 5° or 4°</td>
</tr>
</tbody>
</table>

-7° going upward toward 0°
sector near the end of SR 1832 through 1836. A positive sector appears near the beginning of SR 1836 and grows larger in the first half of SR 1837. Southern latitudes were entered just as the positive sector at the end of SR 1836 begins. Figure 5 shows histograms of $B_r$ and $B_\phi$ near the maximum latitude reached, 4.5°. The radial dependence of the magnetic field has also been estimated from the Mariner 5 data [Coleman and Rosenberg, 1968].

One solar rotation period in 1968 is covered by the magnetometer data available from the earth satellite, OGO 5, which is in interplanetary space during about half of each 64-hour orbit. The available data were taken over the latitude range at $-7^\circ$ to $-5^\circ$ and were found to have a positive polarity percentage of at least 60%. Therefore, data from the four spacecraft studied above support the dominant polarity effect, as defined at the outset.

**OTHER OBSERVATIONS**

As mentioned previously, some pertinent features of the estimated trajectories of other spacecraft are also listed in Table 2. Earth satellites are, of course, constrained to have the same ‘mean’ motion as their ‘guiding center,’ the earth. The orbit of Pioneer 6 was estimated by assuming that the spacecraft remained in the plane of the ecliptic and by using the information [Ness and Taylor, 1968] that it was at 0.83 AU and at a longitude of some 44° ahead of the earth on July 8, 1966.

Data from the earth satellite, IMP 1, provide broken coverage of an interval during which the earth was at southern latitudes between 0 and $-5^\circ$. Using 5.46-min averages, the IMP 1 experimenters made a histogram showing that the positive polarity was 48% and the negative polarity was 35% [Ness et al., 1966], with the rest of the data in the second and fourth quadrants.

The sector pattern recorded with the satellite IMP 2 [Fairfield and Ness, 1967] is similar to that of IMP 1 for several solar rotations. However, the polarity data of IMP 2 in Figure 1 are over 50% negative at northern latitudes.

The measurements taken with IMP 3 showed a dominance of negative polarity in the interplanetary field at northern latitudes. Figure 6 of Ness and Wilcox [1967] shows a histogram of the direction of the component parallel to
the ecliptic plane as given by the 5.46-min averages. Negative polarity is very dominant. Figure 1 also shows that the negative polarity was dominant in the IMP 3 data.

In the Pioneer 6 measurements, the dominance of the positive polarity was apparent at southern latitudes. This dominance apparently increased as the spacecraft approached more southern latitudes. It then decreased noticeably as northern latitudes were approached. Burlaga and Ness [1968] made a histogram of hourly averages showing that the field had 49% positive polarity and 41% negative polarity (the rest were in the second and fourth quadrants) for the period from December 16, 1965, to September 29, 1966. The spacecraft was at southern latitudes until the first half of May 1966, when it entered northern latitudes. At northern latitudes the polarity was predominantly negative.

Explorer 33 measurements clearly show a predominance of positive polarity in the first half of 1967 (southern latitudes). The Explorer 35 measurements show a predominance of negative polarity at northern latitudes. The length of the larger of the positive sectors increases as southern latitudes are traversed. Preliminary OGO 5 satellite data show that by March 1968, the polarity had become at least 60% positive.

An additional test for the dominant polarity

<table>
<thead>
<tr>
<th>YEAR</th>
<th>THE Pitt</th>
<th>MARINER 4</th>
<th>MARINER 5</th>
<th>OVERLAPPING 27 DAY AVERAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>32548</td>
<td>1798 1799</td>
<td>1832 1833</td>
<td>1767 1768 1769</td>
</tr>
<tr>
<td>1963</td>
<td>278</td>
<td>1800 1801</td>
<td>1834 1835</td>
<td>+7.5° +7.5° +7.5°</td>
</tr>
<tr>
<td>1964</td>
<td>308</td>
<td>1802 1803</td>
<td>1836 1837</td>
<td>-7.0° -7.0° -7.0°</td>
</tr>
<tr>
<td>1965</td>
<td>359</td>
<td>1804 1805</td>
<td></td>
<td>+10° +10° +10°</td>
</tr>
<tr>
<td>1966</td>
<td>259</td>
<td>1806 1807</td>
<td></td>
<td>-12° -12° -12°</td>
</tr>
</tbody>
</table>

The values plotted are those for overlapping 27-day intervals taken every three days. The days of the year and the latitudes of the spacecraft shown are for the midpoints of each 27-day period. The bottom graph is the Mariner 2 data redone to account for data gaps by giving all 293 points per 3-hour interval to the polarity dominant there or in the preceding interval.

Fig. 2. Numbers of measurements of outwardly directed \( B_r > 0 \) and inwardly directed \( B_r < 0 \) magnetic field. The values plotted are those for overlapping 27-day intervals taken every three days. The days of the year and the latitudes of the spacecraft shown are for the midpoints of each 27-day period. The bottom graph is the Mariner 2 data redone to account for data gaps by giving all 293 points per 3-hour interval to the polarity dominant there or in the preceding interval.
effect indicated in the Mariner data is shown in Figure 6. This figure has been constructed using the polarity data shown in Figure 1 from late 1964 onward. For each solar rotation period, the lower bar is the actual number of days of negative polarity. The upper bar is 27 minus the number of days of positive polarity. The distance between the bars is then the number of days of missing data and ambiguous polarity. The dot is simply centered between the bars. A percentage scale (100% · days/27) is also displayed. Where they overlap in time, IMP 2 data were used instead of Mariner 4 data. All of the spacecraft data represented in Figure 6 were recorded at essentially the heliographic latitude of the earth with the exception of the Pioneer 6 data for SR's 1814-1823 and the Mariner 4 data for all but about the first three SR's of the flight (see Table 2).

The sine function plotted in Figure 6 is the least-squares best-fit sine function, with a period of one year, to the curve of the percentage of negative polarity (the dots). The function is $50.9-17.6 \sin (\omega t - 0.171)$, where $t$ is measured in terms of Bartels' solar rotations. The rms deviation of the data points from this best-fit sinusoid is 9.1% (see Table 3).

This best-fit sinusoid may be compared with the approximately sinusoidal function for $\beta$, the heliographic latitude of the earth. Using the same reference time, this function is $\beta(t) = -7.3 \sin (\omega t - 0.085)$, where we have used the small-angle approximation for $\beta$ since $-7.3^\circ < \beta < 7.3^\circ$. The phase difference between this function and the best-fit sinusoid for the percentage of negative polarity is only 0.085 radians or about 5°. Thus, the best-fit sinusoid leads $\beta(t)$ by only 5°.

The mean value of the percentage of negative polarity is slightly greater than 50%, although the difference from 50% may not be significant. Nevertheless, since the northern hemisphere of the sun was hotter than the southern hemi-
sphere, this effect may be due to the fact that lines of force from the northern hemisphere (negative polarity) were being pushed across the equatorial plane by a solar-wind flow that was on the average slightly southward across the plane. A nonzero average value of $B_\phi$ may be produced by effects such as the north-south asymmetry in the solar wind [Siscoe and Coleman, 1969] or by magnetic field-solar wind interaction forces. The sign of the net $B_\phi$ should be consistent with the latitude-dependent dominant polarity effect.

**Discussion**

On the basis of the foregoing, we conclude that, during the interval 1962-1968, the dominant polarity of the interplanetary magnetic field was inward at latitudes above the solar equatorial plane and outward at latitudes below. Strictly speaking, this conclusion applies only in the region covered by the measurements, i.e., $0.7 < r < 1.5$ AU, $-7.3 < \beta < 7.3$° latitude.

The dipolar component of the sun's field has exhibited this same polarity, inward at the North Pole and outward at the South Pole, since the last solar maximum. Thus, the dominant polarity effect is at least suggestive of the possibility that the interplanetary field near the orbit of the earth is an extension of the dipolar component of the sun's field.

Although this possibility would seem to be the most straightforward one, there are at least two reasons why it cannot presently be accepted without reservation. First, there is no evidence that the dipolar component contributes to the photospheric field at latitudes lower than 40° to 60°. The dipolar component has been detected only in the polar regions and then only with relatively sensitive magnetographs. Second, there is evidence that changes in the interplanetary field near the orbit of the earth

Fig. 5. Distributions of $B_\beta$ and $B_\phi$ at latitude $\beta = 4.5^\circ$ for August 7 (Day 219 of 1967) to September 2, 1967 (mostly SR 1834).

Fig. 6. Polarity observed by spacecraft having the earth's heliographic latitude. For each solar rotation period (SR) the lower bar is the actual number of days of negative polarity. The upper bar is 27 minus the number of days of positive polarity. The distance between the bars is the number of days of missing data. The dot is centered between the bars. The sine function is the least-squares best-fit function with a one-year period described in the text. As explained in the text, some of the Mariner 4 and Pioneer 6 data were taken at latitudes differing somewhat from that of the earth.

Fig. 6. Polarity observed by spacecraft having the earth's heliographic latitude. For each solar rotation period (SR) the lower bar is the actual number of days of negative polarity. The upper bar is 27 minus the number of days of positive polarity. The distance between the bars is the number of days of missing data. The dot is centered between the bars. The sine function is the least-squares best-fit function with a one-year period described in the text. As explained in the text, some of the Mariner 4 and Pioneer 6 data were taken at latitudes differing somewhat from that of the earth.
are directly related to changes in the presumably nondipolar photospheric fields [Wilcox, 1968; Wilcox and Howard, 1968]. However, in discussing the latter observations, Wilcox [1968] pointed out that 'the interplanetary sector structure may have a solar source in the background photospheric magnetic field patterns which have sufficiently small magnitude that the pattern is marginally detected with the solar magnetograph.' He also cited Bumba and Howard [1965] as having recognized the possibility that there is a background field in the photosphere that is too weak to be detected.

Furthermore, photospheric fields of higher intensity are observed to be more localized, and the lines of force of a weak dipolar field are more likely to be carried out into interplanetary space than those of the more intense and localized field. The reasoning here, essentially that used by Davis [1965] in advancing his nozzle hypothesis, is as follows. Widespread photospheric regions with this very weak, radial, regular background field of one polarity may allow the continuous outflow of particle streams strong enough to cause the magnetic field lines to be stretched out in the direction of the stream. However, the continuous outflow of solar particles from the active areas of the sun is impeded by local strong magnetic fields. The particles in these active regions build up and explode outward only after being heated to relatively high temperatures. These particles produce flare-connected geomagnetic substorms.

The relatively weak magnetic fields, those of less than 1 gauss at the photosphere, are those for which the solar magnetograph may be inadequate. However, after a 1/R^2 power law, a field of 1 to 2 gauss at the photosphere gives 2.5 to 5.0 gamma for the radial components at 1.0 AU. These values are close to the measured averages at 1.0 AU. The measured average increased from 2.4 gamma at solar minimum (Mariner 4) to only 3.5 just before solar maximum (Mariner 5).

All in all, we feel that the possibility of a 'dipolar origin' for the interplanetary field near the orbit of the earth cannot be ruled out. Proceeding along this line, then, Babcock's [1961] model of the sun's magnetic field suggests a number of tests.

In Babcock's model, the photospheric background field, which is composed of the remnants of sunspot-connected bipolar magnetic regions (BMR's), is the source of the dipolar component. The decay of a particular BMR may or may not leave a background field of changed polarity at its location, but the cumulative effect of many BMR's is just a polarity change.

### Table 3

<table>
<thead>
<tr>
<th>( \tau ) (Period, yr)</th>
<th>( A ) (Amplitude of Sine, %)</th>
<th>( \alpha ) (Phase, deg)</th>
<th>( C ) (Mean, %)</th>
<th>( \sigma ) (rms Deviation of Data, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.82</td>
<td>-11.5</td>
<td>82.2</td>
<td>50.8</td>
<td>13.2</td>
</tr>
<tr>
<td>0.84</td>
<td>-13.3</td>
<td>19.0</td>
<td>50.6</td>
<td>12.3</td>
</tr>
<tr>
<td>0.87</td>
<td>-15.4</td>
<td>108.0</td>
<td>50.4</td>
<td>11.0</td>
</tr>
<tr>
<td>0.90</td>
<td>-17.0</td>
<td>-163.3</td>
<td>50.4</td>
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</tr>
<tr>
<td>0.93</td>
<td>-18.2</td>
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</tr>
<tr>
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<td>8.4</td>
</tr>
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<td>50.9</td>
<td>9.1</td>
</tr>
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<td>1.04</td>
<td>-15.7</td>
<td>- 81.0</td>
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</tr>
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<td>51.3</td>
<td>12.1</td>
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<td>51.4</td>
<td>13.5</td>
</tr>
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<td>-147.1</td>
<td>51.2</td>
<td>14.7</td>
</tr>
<tr>
<td>1.22</td>
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<td>-105.4</td>
<td>51.0</td>
<td>15.3</td>
</tr>
<tr>
<td>1.28</td>
<td>- 2.5</td>
<td>50.9</td>
<td>50.7</td>
<td>15.4</td>
</tr>
</tbody>
</table>
date, although the Mariner 2 data suggest that the amplitude of the variation in the percentage of negative polarity was smaller, about 5%, in 1962 than at any subsequent time in the interval studied.

As discussed previously, the dipolar component of the sun's field changed sign at the solar activity maximum in 1958 [Babcock, 1959]. According to Babcock's [1961] model, the field should reverse at each solar maximum. Thus, we would expect the dominant polarity, as recorded near the earth to reverse between 1968 and 1973. We place the end of this interval at 1973 because the phase of the solar cycle will then be the same as it was in 1962 when the Mariner 2 data were taken and because no reversal of the dominant-polarity effect has occurred since 1962.

Still assuming that most of the lines of force with the dominant polarity have their sources in the dipolar component of the sun's field, the question remains as to the source of the lines of force with the nondominant polarity. There would appear to be several possibilities.

First, it is possible that the field lines of nondominant polarity originate in the same hemisphere as those of dominant polarity and that they are either the remnants of the background field of the preceding solar cycle or part of the field developing for the succeeding solar cycle. At near-equatorial latitudes the most likely situation would seem to be that in which the field lines of nondominant polarity are part of the remnant field from solar maximum to solar minimum and part of the new field from solar minimum to solar maximum.

In this case, one might expect the dominant polarity to be most dominant at solar minimum. From solar maximum to solar minimum, solar-wind streams with fields of the nondominant polarity should therefore be older and perhaps less energetic than the streams with the dominant polarity. The opposite situation should then hold from solar minimum to solar maximum.

However, this is not the only possibility. The new field may begin to develop immediately after solar maximum and continue to develop until the next solar maximum by which time it constitutes the new background field. In this case, the polarity dominance would probably be greatest at solar maximum and the streams
with the nondominant polarity would always be younger than those with the dominant polarity.

However, the situation would be more complicated if, as in Babcock's model [Babcock, 1961], the polarity change at equatorial latitudes is out of phase with the change at the poles. A straightforward test between these alternatives is the measurement of the ratio $NBr^+/NBr^-$ at latitudes on both sides of the equatorial plane over a complete solar cycle.

As mentioned previously, the data from the Mariners indicate that the dominant polarity became more dominant between 1962 and 1965, although this trend may not actually be significant. Our reservations about this apparent trend are due to the fact that relatively great geomagnetic activity was associated with some of the solar-wind streams observed during the Mariner 2 flight, so that the polarity of the interplanetary magnetic field that was observed for these same streams may have been anomalous.

The consideration of geomagnetic activity leads us to still another possibility, namely that the lines of force of nondominant polarity have origins in regions on the opposite side of the equator and cross the equatorial plane as they are dragged into interplanetary space. This distortion could occur if the solar-wind streams carrying these field lines come from relatively hot spots on the sun so that, being considerably more energetic than the surrounding streams, they expand more (with distance from the sun) than their neighbors. Since all of the measurements considered here were taken within $8^\circ$ of the solar equatorial plane, such streams could probably contribute significantly to the solar-wind encountered by the spacecraft.

Mariner 2 encountered a relatively broad sector of positive polarity, although the dominant polarity for the entire solar rotation period was negative. Since the Mariner 2 data were taken at northern latitudes, the dominance of negative polarity is consistent with the dominantly-polarity effect as observed later in the solar cycle. From Figure 1 it is seen that a relatively high $Kp$ (or the related $C9$ index) geomagnetic index was associated with the beginning portion of this positive sector. Since this sector was quite wide, lasting 12 days, there is some question as to whether its source could be considered to have been localized. It is possible that a rather broad region of enhanced solar activity in the southern hemisphere was responsible for this sector.

In the sunspot cycle beginning at the activity minimum in 1964, the northern hemisphere of the sun has been hotter than the southern hemisphere [Livingston, 1966]. This asymmetry existed in previous years as well [Bell, 1961]. The greater northern activity should tend to push the solar wind southward causing fields originating in the northern hemisphere to be observed in the southern hemisphere [Wilcox, 1965]. It should depress the plane separating the two dominant polarity regions below the solar equatorial plane. This north-south asymmetry may account for the fact that the dominance of the positive polarity recorded during the Mariner 4 flight decreased considerably while the spacecraft was still at southern latitudes. It also may account for the fact that IMP 1 and Mariner 4 at $0^\circ$ to $3^\circS$ latitude observed the same sector pattern as that of IMP 2 at $8^\circN$. In fact, the geomagnetic activity index was consistently very high throughout 1964 for certain sectors, and solar magnetograms [Livingston, 1966] also show increased northern activity at appropriate locations and times.

Interplanetary magnetic fields observed at times of very high geomagnetic activity contain contributions from nondipolar photospheric fields that sometimes may even be seen on solar magnetograms. This situation may also be reflected in atypical polarity percentages at such times.

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References


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