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MAGNETIC FIELD OF THE PLANET VENUS*

by

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Abstract

Statistical plots of daily equivalent planetary amplitude Ap, similar to magnetic character figure Ci, for 50 days before and 50 days after every inferior conjunction of Venus during the years of low sunspot activity over the period 1884-1955, show that there is a marked decrease in the value of geomagnetic activity about 2 days before the date of conjunction. This asymmetry of the decrease around the date of conjunction suggests a deflection of solar corpuscles by Venus, thereby indicating the presence of some magnetic field surrounding the planet.

Assuming, according to Störmer, an equatorial ring current of about 1 million kms. radius around the earth, the value of the polar magnetic field of Venus works out to about 0·4 gauss. Alternatively, if we assume a ring current of about 10 earth radii according to Martyn, the polar magnetic field of Venus becomes 0·024 gauss.

The above values have been used for computing the rotation period of Venus, assuming that Blackett's empirical formula is applicable to this case. The rotation periods thus obtained are 2 days and 24 days respectively. These values are in better agreement with the faster rotation with a period of a few days estimated by some astronomers than with the much slower rotation with a period of 225 days obtained by others.

Similar analyses in the cases of Mercury and Moon give no sure indication of the existence of magnetic fields on these bodies.

Introduction

The concept of streams of corpuscles of solar origin is now established since Birkeland[1] had showed that certain auroral features could be explained on the basis of charged solar corpuscles entering the polar latitudes after being deflected by the earth's magnetic field. If the planet Venus also has a magnetic field similar to that of the earth, it would influence the normal passage of corpuscular streams from the sun to the earth at times of inferior conjunctions of Venus. The variation in the corpuscular intensity would then reflect itself in the earth's magnetic activity. On such considerations, Houtgast[2] has recently shown in a very interesting manner, that there is indication of the existence of a magnetic field on Venus. To arrive at some systematic variation in the magnetic activity of the earth around the dates of inferior conjunctions of Venus, he used the International Daily Magnetic character figure, Ci, from 1884 to 1953[3] and found that there was a decrease in the earth's magnetic activity from seven days before to one day after conjunction, during the years of low sunspot activity. The asymmetry of decrease around the date of inferior conjunction was supposed to be due to a deflection of corpuscular streams coming from the sun towards the earth, by the magnetic field of Venus.

Analysis of Data.—In the present investigation the method of statistical analysis adopted is very similar to that followed by Houtgast. However instead of the classical International Daily Magnetic character figure Ci, which is a measure of the combined effect of both the wave radiation (generally much higher) and the corpuscular radiation from the sun on the earth's magnetic field, the writer has chosen a new parameter called the daily equivalent planetary amplitude, Ap, in units of 2γ, based on the three-hourly K-indices which represent mainly the effect of the solar particle radiation on the intensity of geomagnetic activity. Ap has a linear

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scale and has, therefore, been preferred to Kp indices having a quasi-logarithmic scale. This new parameter is one of the three measures (*viz.* Kp, Ap and C) of the time-variations of the intensity of geomagnetic activity, proposed by the International Association of Geomagnetism and Aeronomy. Daily values of Ap, published by Bartels and Veldkamp[4] are available regularly from 1937 onwards and for values prior to 1937 (except 1932/33) a rough conversion of Ci into Ap has been made according to the following table[5] :—

Ci	0·0	0·1	0·2	0.3	0·4	0.5	0·6	0·7	0·8	0·9	
Ap	2	4	5	6	8	9	11	12	14	16	
Ci	1·0	1·1	1·2	1.3	1·4	1·5	1·6	1·7	1·8	1·9	2·0
Ap	19	22	26	31	37	44	52	63	80	110	160

There were forty-five inferior conjunctions of Venus during the period 1884-1955. The dates and the angular distances, d, between Venus and the Sun at the moments of conjunctions were collected from the corresponding Nautical Almanacs. From among these conjunctions those which occurred during the years of low solar activity have been chosen for analysis, because during such years the effect of the solar corpuscular streams on the magnetic activity of the earth will be comparatively more marked, while during years of greater solar activity the relative effect of the solar ultra-violet and X-radiation will increase much more strongly and sometimes mask the corpuscular effect completely. The annual mean sunspot number R has been taken as a measure of solar activity of the year. In order to detect more easily the influence of Venus on the corpuscular stream, the inferior conjunctions with small angular distances between Venus and the Sun have also been considered.

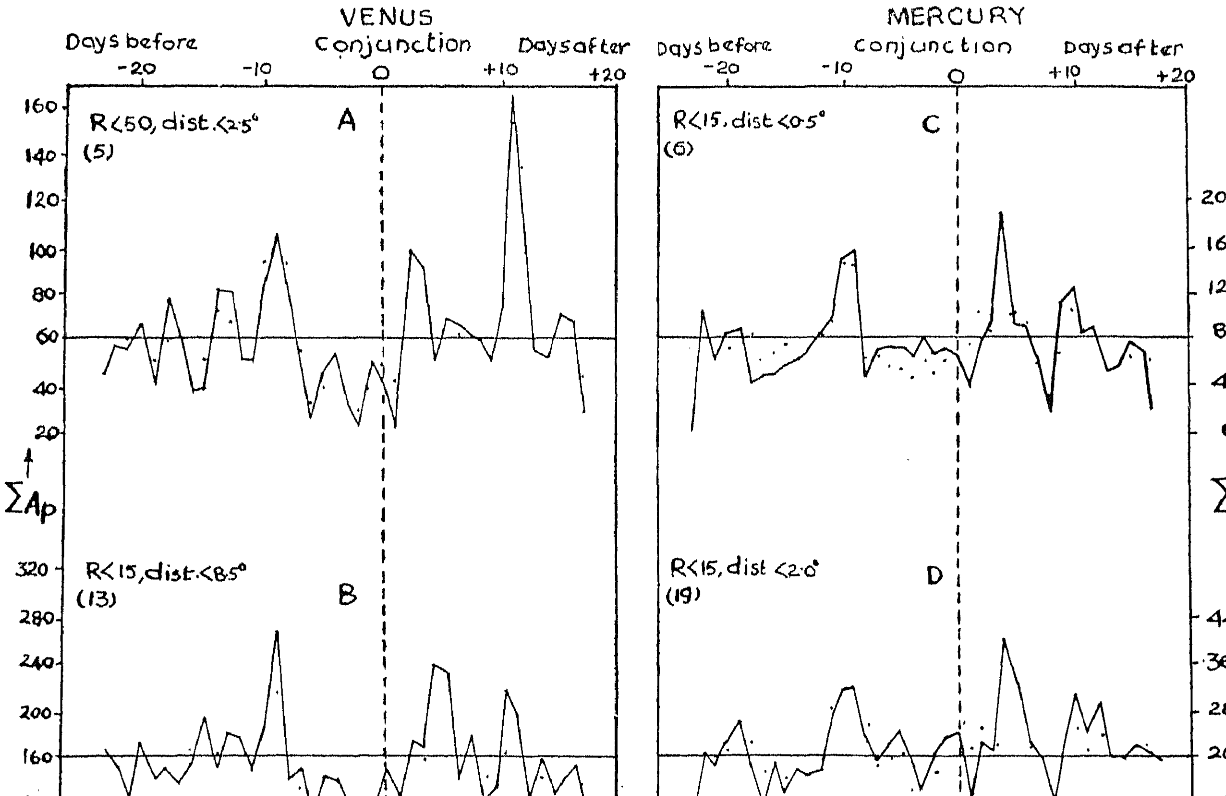

Fig. 1

In the case of Venus two groups of conjunctions A and B were considered. In A, there were 5 conjunctions with R<50 and d<2·5 and in B, there were 13 conjunctions with R<15 and d<8·5. In both the groups Ap figures were tabulated for all the dates of conjunctions and also for 50 days before and 50 days after each date of conjunction, the zero day. In each group the totals ΣAp for each day, from −50 to +50 from the zero day were determined. These totals were plotted against days, and a dip from about 8 days before to 2 days after the date of conjunction was noticed in both the groups. From among these 101 totals, the 27-day recurrent maxima and minima of solar activity are also noticeale in some cases. To avoid the influence of these recurrent phenomena during the period around the date of inferior conjunction, each value of the totals ΣAp was corrected for the average deviation of the values at the 27th day before and after. This correction was applied only for the days during the interval from −23 days to +17 days from the zero day so that the peculiarities found in the curves between the period −10 days to +4 days might not influence the distant parts of the curves. Finally the curves showing the corrected totals from 23 days before and 17 days after the date of inferior conjunction were drawn as shown in diagrams A and B. The small circles which were joined by a continuous curve represent totals ΣAp for each day, corrected for the 27-day recurrent disturbances, and the dots represent the uncorrected direct totals for each day.

Results.—From the curve (B) made up of all the 13 inferior conjunctions of Venus between 1884-1955, when the sunspot activity was minimum, say, when R<15, it is apparent that the maximum decrease in the geomagnetic activity occurred on the 2nd day before the date of conjunction of Venus. This asymmetric decrease around the date of conjunction suggests a deflection of the solar corpuscular stream by the planet Venus, thereby indicating the presence of some magnetic field surrounding the planet. (There is also a small decrease between zero day and one day after conjunction : it is likely that this decrease in intensity is due to the shielding by the planet Venus of the flow of the solar corpuscular stream whose time of travel from Venus to earth, with a velocity of about 500 km. per sec. works out to be about one day.) From the curve A, based on 5 inferior conjunctions only, when R< 50 and d<2·5, the same type of asymmetric decrease in the geomagnetic activity around the zero day is noticed, the decrease being perceptible even from about 7 days before conjunction.

Discussion.—Before attempting to estimate the strength of the magnetic field of Venus from the above analysis let us imagine the mechanism of how the corpuscular stream affects geomagnetic activity. It is well known that in addition to the occasional strong aurorae, weak aurorae are observed on almost every clear night in the polar regions. These weak permanent aurorae suggest that an uninterrupted weak corpuscular radiation reaches the polar regions. But the slow corpuscular radiation cannot penetrate to so near the polar regions as to produce the aurorae, unless some process of acceleration of the corpuscles as suggested by Martyn[6], (1951) exists. In this process a permanent ring current which flows across the magnetic field of the earth plays a major role. It is expected to be formed by the continuous flow of thermal protons from the sun towards the earth in a density of at least 1 proton per c.c. and with velocity of several hundred kms. per second. An idea of the approximate size of the ring may be obtained by the simple but justifiable approximation of equating the pressure $\frac{1}{2}$ Nm U^2 exerted by the solar stream to the pressure $\frac{H^2}{8\pi}$ exerted by the lines of magnetic force, where N is the number density, and m and U the mean mass and velocity respectively of the solar protons, while H is the magnetic field in the equatorial plane of the earth which is equal to $\frac{0 \cdot 33}{Z^3}$, Z being the distance from the centre of the earth in units of earth radii. Taking U=500 km./sec.[8] which is the mean velocity of solar protons during the periods of minimum sunspot activity, the radius Z of the ring works out to be about 10 earth radii.

Störmer also favours the hypothesis of a ring current round the earth with a very large radius to explain certain auroral features and also the production of certain radio echoes of long delay. The particles in the ring are supposed to be circling freely under the deflecting influence of the magnetic field of the earth. The equation of motion of the particles of the ring in the equatorial plane expresses the balance between the centrifugal and deflecting forces $\frac{mv^2}{r} = HeV$ where H is the earth's magnetic field at a distance of r from its centre and m, v and e are the mass, velocity and charge respectively of the particle. But $H = \frac{H_o a^3}{r^3}$ where a is radius of the earth and H_o its equatorial value of magnetic intensity at its surface. For protons with velocity=500 km./sec., r works out to be about 1 million kms. (There are, of course, some serious objections for such a large radius for the ring, mainly because it cannot hold together for a sufficiently long time due to the mutual electrostatic repulsion of its particles of the same sign).

Chapman and Ferraro's[7] theory of magnetic storms also suggests formation of a ring current of about 5 or 6 earth radii around the earth at the time of a magnetic storm. Schmidt also attributes the earth's external field to a somewhat permanent ring current circulating round the earth in the plane of the magnetic equator.

At a distance of about 10 earth radii from the earth, the earth's dipole field (which is there about 10^{-4} gauss) is sufficiently distorted by the steady flow of solar protons, and steady electric fields are set up by the interaction of solar protons and the outer regions of the earth's magnetic field. Slight variations in this electric field due to variation in the total number of protons or their velocities are likely to manifest themselves as minor perturbations in the geomagnetic activity even during quiet periods. Suppose by some mechanism the steady flow of protons from the sun is cut off from approaching the earth, the external component of the geomagnetic activity due to particle radiation will naturally be diminished. This is what exactly has been noticed just a few days before the inferior conjunction of Venus. The parameter, Ap, which has been chosen for analysis is a sufficiently good index of particle radiation from the sun, and the period selected is one of low sunspot activity when the corresponding effect of wave radiation on geomagnetic activity is not so exceptionally high as to mask the comparatively small effect of particle radiation.

Even though it is thought that the magnetic field of Venus is responsible for deflecting the solar corpuscular stream from the earth, the estimation of its exact magnitude is not simple. Firstly, the motion of the stream is three-dimensional, secondly the properties of the particles are so very little known. Under these circumstances it is difficult to calculate the influence of the magnetic field on such a corpuscular stream. Making certain simple assumptions, a rough idea of the strength of the magnetic field of Venus, is, however, obtained from the results of the analysis described in this paper. The magnetic field of Venus is supposed to be a dipole field with its magnetic axis perpendicular or nearly perpendicular to the plane of its orbit, as in the case of the earth. Let the north poles of the earth and Venus appear uppermost as viewed from the sun. Then a positively charged particle, say, a proton, moving from the sun towards the earth in or very nearly its equatorial plane will, jute a few days before the date of inferior conjunction of Venus, have to pass near Venus. If Venus also has a magnetic field like that of the earth, the particle will be deflected from its normal motion towards the earth and will bend round the planet Venus. The amount of deflection will depend upon the strength of the dipole field at such a distance from Venus; the speed of the particle, of course, will not change.

Now from the diagram B, it is noticed that a marked decrease in geomagnetic activity occurred about 2 days before the inferior conjunction of Venus. If we assume a velocity of about 500 km/sec. for the solar proton it takes nearly a day to travel from Venus to earth. So the deflection of the charged particle by Venus must have occurred about 3 days before inferior conjunction. Then the distance of the stream from Venus will be about $5 \cdot 5 \times 10^6$ km. To form an idea of the amount of deflection, we have now to examine how far away from the earth the particle has to be removed in order to become unimportant in contributing to the external component of the geomagnetic activity which is supposed to be due to a ring current. If we assume a radius of about 10 earth radii for the ring, according to Martyn, the deflection of the stream by the magnetic field of Venus at a distance of about $5 \cdot 5 \times 10^6$ km. will be about 1/5 of a degree; but if we assume a ring of about 1×10^6 km. radius, according to Stormer, the deflection of the stream will be about 3°.

Using the formula $H\,(r_o) = \frac{mc}{2e} \cdot \frac{V}{r_o} \cdot \text{Sin}\ \alpha$, the magnetic field $H(r_o)$ at a distance r_o from Venus can be evaluated substituting the values of m, v and e the mass, velocity and charge respectively of the particles,—in this case, protons—, α the angle of deflection of the corpuscular stream, and C the velocity of light.

From the value of $H\,(r_o)$ the polar field Hp of the planet can be obtained from the formula $Hp = 2H(r_o)\left(\frac{r_o}{a}\right)^3$ where a is the radius of the planet.

If we take the value of α equal to 1/5 of a degree the polar magnetic field Hp for Venus comes out to be about 0·024 gauss, but if α is taken to be 3°, the value of Hp becomes about 0·4 gauss. The value of Hp, in the case of the earth is 0·7 gauss.

Rotation period of Venus.—If now we assume Blackett's formula[9] $P = \frac{\beta G^{\frac{1}{2}}}{2C} . U$. (where P is the magnetic moment, U the angular momentum of a large rotating body, G the gravitational constant, C the velocity of light and β a constant of the order of about 0·3 in the case of the earth), which was found to hold good in the case of three astronomical bodies *viz.*, the earth, the sun* and 78-Virginis, to be also applicable to the case of Venus, we can compute the axial rotation period of Venus using the above values of the magnetic field.

The rotation periods thus obtained taking $H_p = 0 \cdot 024$ gauss and 0·4 gauss are about 24 days and about 2 days respectively.

The exact rotation period of Venus is still unknown. Schiaparelli and others and very recently A. Doll fus[10] have found from extensive visual observations of the dusky markings of Venus that the planet rotates around its axis in a 225-day period which is also its orbital period. But G.P. Kuiper[11] from a photographic study of the planet has recently come to the conclusion that its axial rotation is very rapid and cannot be more than a few weeks at the most. Spectroscopic evidence by V.M. Slipher[12] and radiometric observations by Pettit and Nicholson[13] of the small difference in temperature between the sunlit and the dark hemispheres of the planet also rule out the possibility of its rotation period being more than a month. W.H. Pickering[14] obtained a value of about 3 days for its period of rotation by continuous observation of the apparent motion of two very conspicuous spots on the planet. E .J. Opik[15] has estimated that the period of rotation will be about 10 days, as a compromise between the radiometric observations of nocturnal cooling and the presence of the banded pattern as indicative of the coriolis force being a noticeable factor in the atmospheric circulation of Venus. Very recently J. D. Kraus[16] from radio-astronomical observations at a wave-length of 11 metres deduced a value of about 22 hours as the rotation period of Venus.

The values for the rotation period obtained by the analysis described in the present work are in better agreement with the faster rotation period of a few days or weeks rather than with the much longer period of 225 days.

As already mentioned, the problem in general is much too complex to make exact quantitative calculations. The magnetic field of Venus deduced by the above method is only approximate and can give only the order of magnitude.

A similar analysis has been done in the case of Mercury, the curves of which are reproduced in Fig. 1 (C and D). Although there is some similarity between the curves for Venus and Mercury, it is difficult to have even a rough estimate of the strength of the magnetic field of Mercury, from the curves C and D. The magnetic field of Mercury, if there is any, is too small to be estimated by the above method of analysis.

A preliminary analysis on similar lines in the case of the moon did not show any indication of magnetic field.

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*When Blackett put forward the above formula, the sun was also believed to have a general magnetic field of about 53 gauss at the poles; but later observations appear to make the existence of this field doubtful.

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EDITOR'S NOTE

The problem of the origin of a *general* (as distinct from *local*) magnetic field on astronomical bodies has exercised the minds of many theorists for a considerable time. The first idea of the existence of a general magnetic field on the sun appears to date back to Bigelow (1889). In 1912-13 Hale thought that he had actually measured this field on the sun, the value deduced by him from his measurements at heliographic latitude 45^0 being about 50 gauss at the pole and 25 gauss at the equator; but during the minima of 1922 and 1932 when he and his collaborators repeated these measurements there was no sure evidence of its existence. Later in 1946 Thiessen using an interferometric method, which was capable of far greater accuracy than Hale's spectrographic method, claimed to have confirmed the existence of the solar general magnetic field, the value at the pole derived by Thiessen being 53 ± 12 gauss. However, working under better observing conditions in 1947-48 Thiessen found that the field was at most of 5 gauss, which was of the order of the possible errors of observation. Again, in 1949 using a finer technique than before the same investigator noticed that the general magnetic field of the sun had changed sign and its intensity was no greater than $1\cdot5 \pm 0\cdot5$ gauss. H.von Klüber also observing in 1949 came to the conclusion that the sun's general magnetic field was not observable by his technique, and that if the field existed at all its value was certainly less than 1 gauss. In more recent years (1952-53) H. W. Babcock and H.D. Babcock have developed a highly sensitive Solar Magnetograph capable of recording continuously surface fields as small as 1 gauss with the help of a cathode-ray oscillograph and a photographic camera. Local fields of very variable intensities have so far been detected by this instrument ; whether these local fields really derive from a general magnetic field of the sun can be decided only when a continuous series of measurements extending over a long period becomes available.

One might attribute the discrepant observations to a genuine variability of the solar general magnetic field; but in the absence of any regularity in the observed variations and in view of the fact that the observed intensity of the field is at the limit of observability it would be more reasonable to conclude that there is yet no real evidence of the existence of a solar general magnetic field. From ordinary considerations also such a conclusion would be permissible, for a general magnetic field is unlikely to exist at the temperature of the sun. However, the magnetic stars observed by H.W. Babcock prove that even at the higher temperatures prevalent on certain stellar bodies magnetism can exist, although the mechanism which gives rise to and maintains the magnetic field on these stars is not known with any degree of certainty. It is to be noted however that the magnetic fields, observed by Babcock on the rapidly rotating hot A-type stars, are of an altogether different order of magnitude ranging, as they do, between 1500 and 5500 gauss, or more. Despite the fact that there is yet no satisfactory theory of the origin of the general magnetic field of the earth, it would be easy to understand that the magnetism of the earth, by whatever process it might have come into being, could persist at the low temperature obtaining on it. It would be equally easy to believe that the other solid bodies of the solar system, such as the Moon, Venus, Mars etc., could retain their general magnetism once it had been brought into existence by some process however obscure at the present time.

During the last 50 years or more there have been many theoretical suggestions regarding a mechanism to which the general magnetic field of astronomical bodies might be attributed ; among these can be mentioned the attempts by theorists such as Larmor, Chretien, Gouy, Decombe, Mariani, Prunier, Giao, Elsasser, Cowling, Bullard and a few others. Electric charges capable of producing magnetic fields appear as a consequence of Decombe's theory (1922) of gravitation, from which he derives particularly a relationship between the magnetic moment of a celestial body and the angular momentum of its axial rotation. But a novel idea was put forward in 1923 by H.A. Wilson who postulated that even an electrically neutral body, like an electric charge in motion, could produce a magnetic field as a consequence of its motion. From this postulate Wilson deduced a relation between the magnetic moment and the angular momentum of an astronomical body,—a relationship very similar to that derived by Decombe and equally capable of yielding the right order of magnitude for the earth's magnetic field and for the Hale-Thiessen solar magnetic field. In 1947 P.M.S. Blackett revived this type of idea once again by very forcefully drawing attention to a yet undetected connection between electromagnetism and gravitation. He pointed out that the ratio of magnetic moment (P) to angular momentum (U) of a rotating neutral mass divided by the ratio of magnetic moment (μ) to angular momentum (u) of the Bohr magneton is a numerical constant very nearly equal to $\frac{m}{e} \sqrt{G}.\ \beta$ where e=charge of the electron, m=mass of the electron, G= gravitational constant and β is a numerical constant depending upon the rotating body concerned. From this he derived his formula connecting the magnetic moment to the mechanical moment of a celestial body rotating about its axis. This formula appears to fit the cases of the earth and the star 78 virginis, and would fit the sun also if it had a field of the order of 50 gauss at the pole.

For reasons considered at the beginning of this note one may not claim that Blackett's formula applies to the sun ; nor need its apparent applicability to 78-virginis be considered to be a confirmation of its validity. But the formula appears to have such an inherent theoretical plausibility that it cannot be brushed aside as purely hypothetical without a more careful consideration of its applicability or otherwise to other cases. It would be of considerable importance to examine whether it fits the Moon, Mercury, Venus and other solid bodies of the solar system. For this purpose one must have a reliable estimate of the speed of rotation and of the magnetic moment in each individual case ; unfortunately, our observational information in this respect is extremely inadequate. In the case of the moon we know the rotational period with great accuracy, but our observational knowledge of the magnetic field, which is expected theortically to be about 1/600th of that of the earth, is practically *nil*. It is to be hoped that observations from artificial satellites and moon probes will eventually provide the necessary data at present lacking. Meanwhile, one must keep an open mind with regard to Blackett's gyromagnetic theory. From this standpoint it is at least interesting that, as is apparent from the foregoing paper, Blackett's formula leads to a rotation period for Venus which is in quite good agreement with the values derived from certain modern observations ; this agreement might even constitute a support, though indirect, for the the gyromagnetic theory of origin of the magnetism of celestial bodies.

January, 1959. **A. K. Das.**

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