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# On the Polar Coronal Rays of the Sun

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**Abstract**

A study of the polar coronal rays made on two eclipse photographs is presented. From the frequency distribution of polar rays, it is shown that the maximum distribution of polar rays occurs in an annular zone around 10° from the poles and a minimum at the poles. From the orientation of the polar rays the length of the hypothetical bar magnet has been determined. A variation in the length of the hypothetical bar magnet with the phase of solar activity cycle is confirmed.

## 1. Introduction

Campbell, Moore and Bell (1923) were the first to point out the similarity between the polar coronal rays and a bar magnet. They showed that the distribution and orientation of polar rays matches fairly well with the magnetic lines of force due to a bar magnet, situated inside the sun and whose poles are separated by two thirds of the sun's diameter. In recent years, Waldmeier (1961), Bachmann (1957), Saito (1958, 1965), Stoddard, Carson and Saito (1966) and Suda (1966) have studied the geometry of the polar rays and tried to correlate with the magnetic lines of force due to a bar magnet. Saito (1965) has shown from a study of several eclipse-photographs that the length of the hypothetical bar magnet is a function of the solar activity cycle.

For further verification of the hypothetical bar magnet, it is necessary to analyse as many large scale eclipse photographs as possible. In the plate collection of the Kodaikanal Observatory, we had two large scale eclipse photographs, obtained during the total eclipse of 1898 and 1922. In this paper we have presented a study of the orientation and the frequency distribution of the polar rays, made on these two eclipse plates.

## 2. Observational data

*The eclipse of 1898 January 21.* This photograph obtained by Michie Smith at Sahdol, Central India (Lat.=23°16′N, long.=81°21′E), using a camera of 15cm aperture and 12 metres focal length, giving an image scale of

16".5/mm. The polar rays could be traced out to distances of the order of 1.2 solar radii as measured from the sun's centre. A high contrast copy of the original negative was enlarged and projected on a screen to obtain an image scale of 3".9/mm. The outlines of individual polar rays were drawn independently by the two authors. A comparison of the two drawings showed no significant difference. A copy of the eclipse photograph obtained by the Lick 1898 eclipse expedition with a similar focal length camera, was generously made available by Director, Lick Observatory, and a comparison of the two pictures showed that almost all polar rays were common on both pictures. Another small scale plate (1'.5/mm), made available from the Lick collection showed polar rays, extending upto 1.6 R. The small scale plate was enlarged to yield an image scale of 3".9/mm and both small and large scale plates were combined to give a composite drawing of the polar rays, as shown in Figure 1. The polar rays were extended from the limb of the moon to meet the solar limb.

At the time of the eclipse the apparent semidiameter of the sun was 16'.14".8 and that of the moon was 16'.24.3. The position angle P of the sun's axis was—7° and the heliographic latitude of the sun's centre, $B_0$ was −5°. The north-south orientation on the plate was determined, using the position angle of the prominences seen on the plate. According to the Lundendorff definition the phase of the solar cycle at the time of eclipse was —0.46. On this photograph 20 north polar rays (N.P.R.), and 30 south polar rays (S.P.R.) were distinctly seen. The number of the polar rays in 5 degree intervals of the polar angle is given in Table I and a histogram in Figure 2. A distinct peak in the histogram is seen at 10°—15° zone of the polar angle.

*The eclipse of 1922 September 21.* This plate was obtained by John Evershed (1922) at Wallal, Western Australia, (Lat.=19°.46'S, Long.=120°.41'E), using a 30cm aperture and 6.3 meter focal length Cooke triplet lens, in conjunction with a coelostat. The image scale on this plate was 33".4/mm. The plate was partly fogged, but for our purpose of determining the geometry of the polar rays the plate was usable. As in the case of the 1898 eclipse plates, this plate was enlarged and projected to yield an image scale of 4"/mm. The outlines of the individual coronal polar rays were drawn and are shown in Figure 1.

At the time of totality the apparent semidiameter of the sun was 15'.56".0 and that of the moon was 16'.43".6. The position angle P of the sun's axis was +25.3° and $B_0$ was +7°. The north-south orientation was determined from the symmetry of the polar rays. The assumption is made here that the magnetic poles and the rotation axis of the sun are in good coincidence (Campbell *et al* 1923). At the time of eclipse the phase of the solar activity cycle was - -0.14. 18 polar rays in the north and 17 in the south were identified on the plate. The polar rays in the south were not as clearly seen as in the north, probably because the sun's south pole was tipped away from the observer ($B_0$=+7°). We give in Table I the number of rays in each of the 5° intervals of the polar angle.. A histogram showing the distribution of the polar rays is given in Figure 2. This shows a peak at (5°—10°) zone of polar angle and a minimum at the pole.

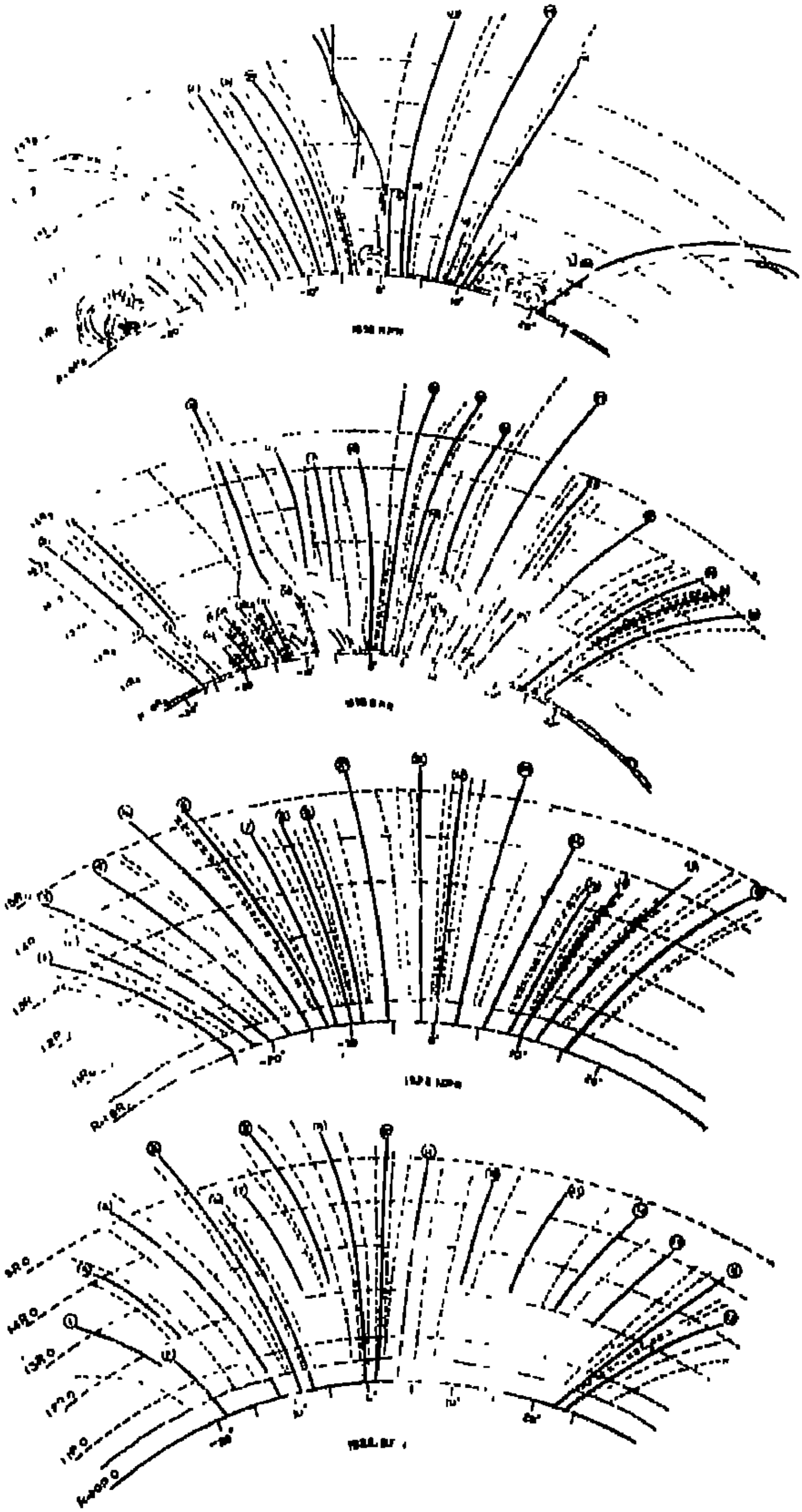

Fig. 1

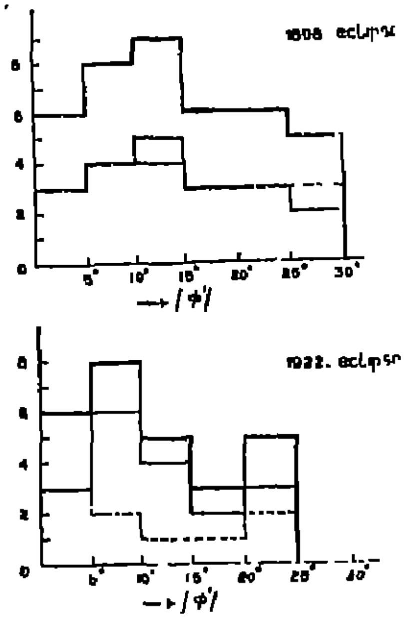


Fig. 2

From Saito's (1958, 1965), data for 6 eclipses and from these two eclipses, we conclude that there is no apparent relation between the position of the polar angle of the peak in the histogram and the solar activity cycle. But during all phases of the solar cycle, the polar rays are consistently seen to avoid the poles of the sun. On the contrary Tsubakia *et al* (1964) have shown in the case of the 1962 eclipse, that the distribution of the polar rays is a maximum at the poles and a minimum near the (12° – 15°) zone, while for the same eclipse of 1962, Saito (1965) has obtained a maximum at the 10° zone and a minimum at the pole. Saito has explained this discordance in the two results as due to the statistical error introduced by Tsubaki *et al*, because they had chosen smaller intervals of the polar angle. From these observations it appears that polar rays are distributed in an annular zone 10° away from the pole. In this connection it is interesting to note that, on examining the prominence data from the Kodaikanal Observatory Bulletins for several solar cycles, there is a tendency for prominences to persist around ±80° latitude and to avoid the poles. However, recently Harvey (1965) from study of the 1963 eclipse photographs, has found a correlation between the polar rays and surface features observed in $K_3$ spectroheliograms and has taken this correlation to establish the close association between polar rays and surface magnetic fields.

### 3. Apparent orientation of the polar rays

*1898 eclipse:* The apparent angle of obliquity Ψ and the polar angle Ø were measured at the limb of the sun and also at distances of 1.1 $R_o$, 1.2 $R_o$, 1.3 $R_o$, 1.4 $R_o$, 1.5 $R_o$, 1.6 $R_o$, from the sun's centre. Ψ denotes the apparent angle between the tangent drawn at a point P on polar ray and the radius vector, and Ø is the apparent polar angle of the point P as measured from the N-S axis. It has been shown by several authors, on the basis of observations, that a linear relation of the form Ψ=k Ø exists between Ψ and Ø and that the parameter k depends on the phase of the polar activity cycle.

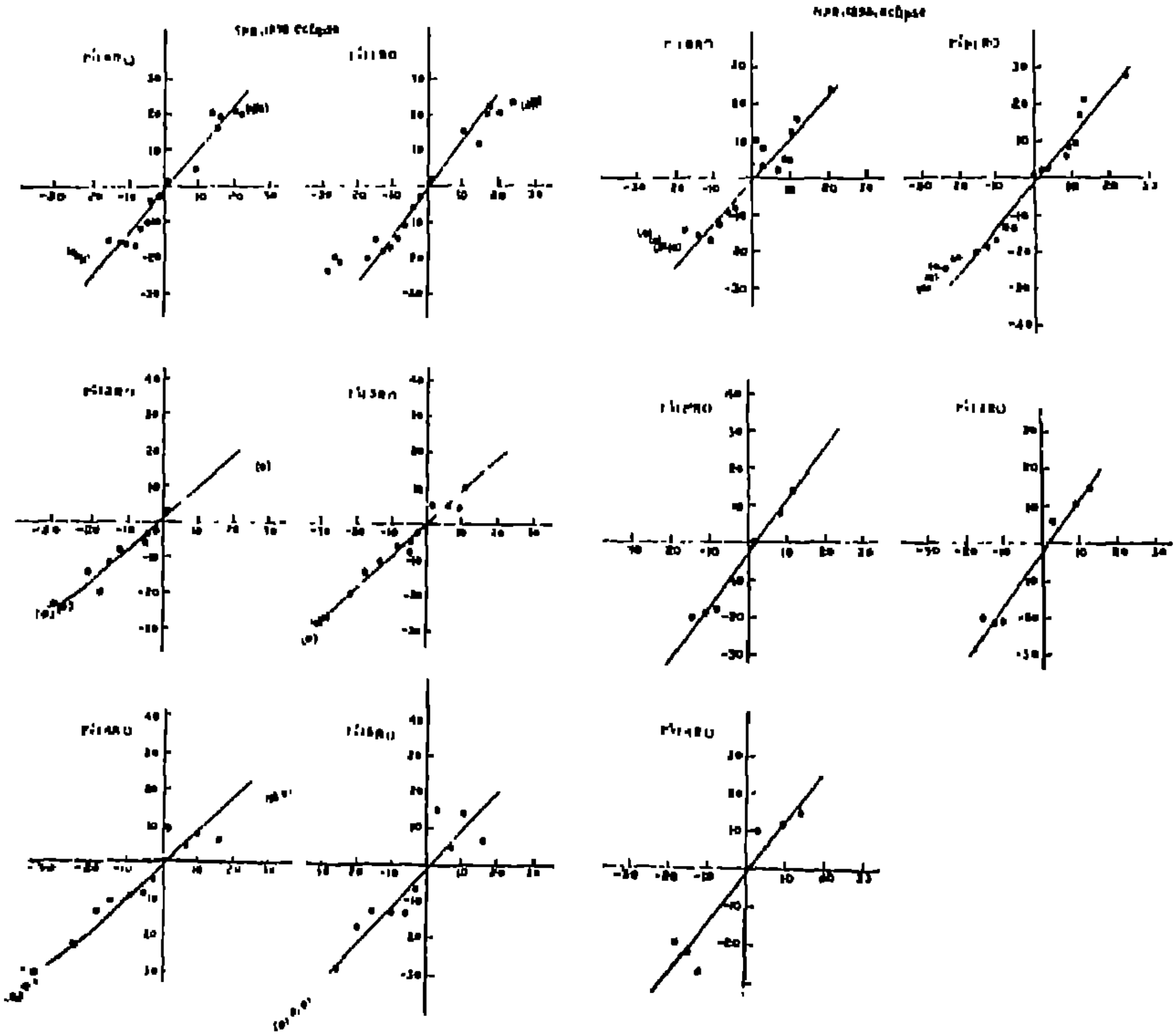

Fig. 8 (l)

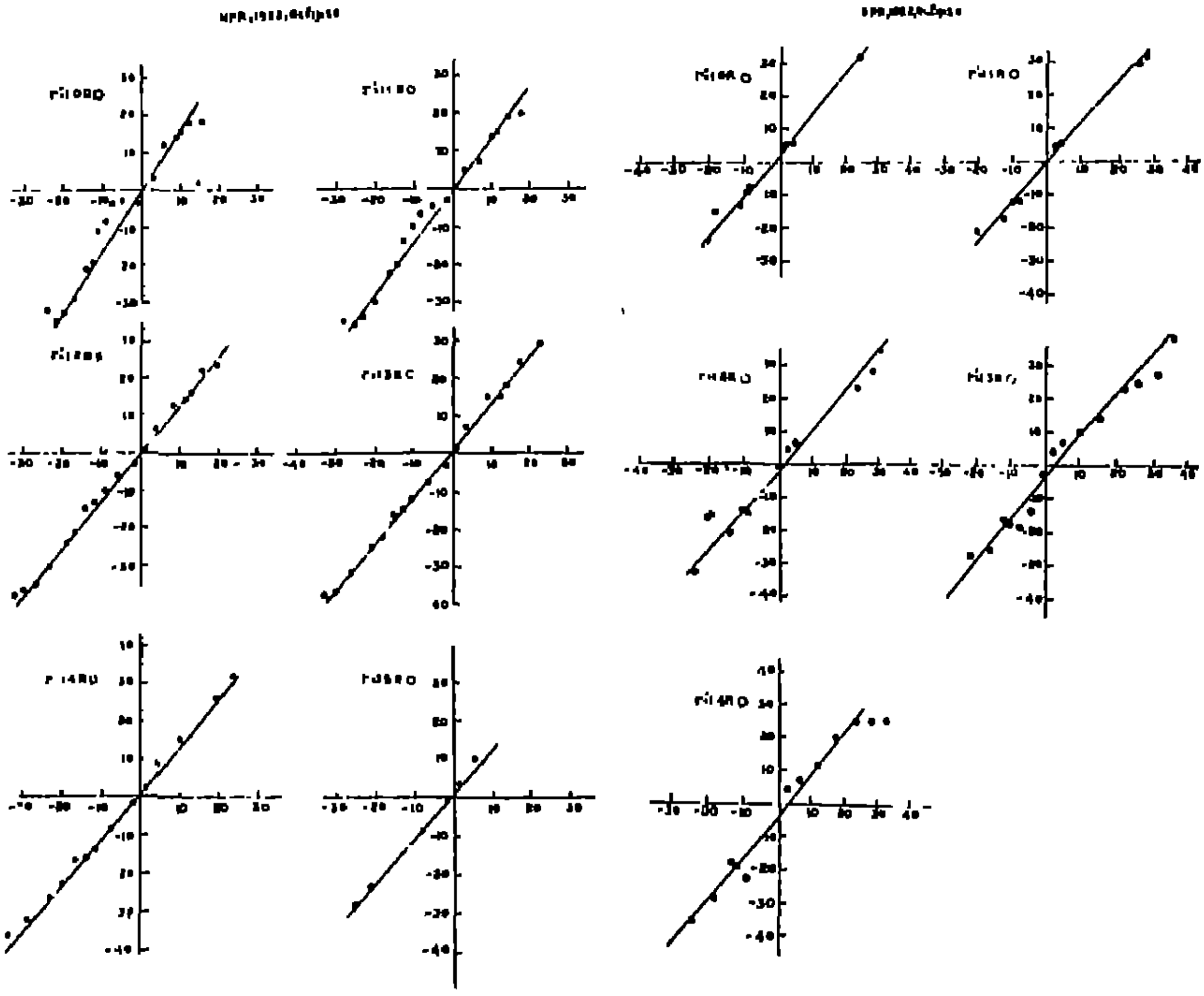

Fig. 3 (ii)

In Table 2a and 2b we give the apparent obliquity and polar angle for each of the polar rays and at several distances from the sun's centre, for both north and south solar polar regions. These are plotted in Figure 3. A few polar rays seem to have been influenced by the local prominence activity and the points are enclosed in parentheses. In Figure 4 is shown the variation of parameter k with the radial distance from the sun's centre. In the north polar region, k shows an increasing tendency with distances upto 1.2 $R_o$ while in the south side, k shows a peak at 1.1 $R_o$ and then a steep decline till 1.2 $R_o$ after which it remains constant.

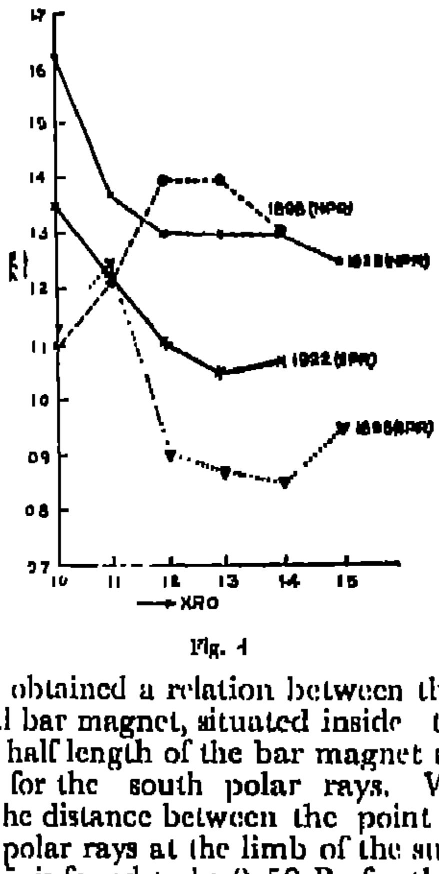


Fig. 4

Saito (1958) has obtained a relation between the parameter k and the length of a hypothetical bar magnet, situated inside the sun. Using Saito's relation, we obtain the half length of the bar magnet as 0.43 $R_o$ for the north polar rays and 0.46 $R_o$ for the south polar rays. We have measured the parameter $\bar{q}$, which is the distance between the point of intersection of the tangents drawn on the polar rays at the limb of the sun and the centre of the solar disc. The mean $\bar{q}$, is found to be 0.50 $R_o$ for the system of N.P.Rs and 0.48 $R_o$ for the S.P.Rs. The two values are in close agreement and we can consider that the two poles of the hypothetical magnet are equally separated apart from the sun's centre. The half-length of the bar magnet according to Saito is in fair agreement with the parameter $\bar{q}$.

*1922 eclipse* : The apparent angle of obliquity Ψ and the polar angle ø were measured on the drawings of the polar rays. The values of Ψ and ø are tabulated in Table 3a and 3b, and are plotted in Figure 3. The variation of parameter k, with the radial distance from the sun's centre is given in figure 4. In the case of 1922 eclipse the parameter k, decreases with increasing distance from the sun's disc up 1.2 $R_o$ and then remains nearly constant.

Using Saito's relation, the half length of the hypothetical bar magnet obtained from the N.P.R. system is 0.61 $R_o$ and for the S.P.R. system is 0.55 $R_o$. The parameter $\bar{q}$ for the N.P.R. was 0.69 $R_o$ ($\bar{q}_N$) and for the S.P.R. was 0.61 $R_o$ ($\bar{q}_S$). In the case of 1922 eclipse the hypothetical north magnetic pole seems to be nearer to the sun's surface compared to the south magnetic pole. A similar result for the asymmetric location of the hypothetical magnet in the sun, has been obtained by Nesmyanvich (1963), from a study of 38 eclipse photographs.

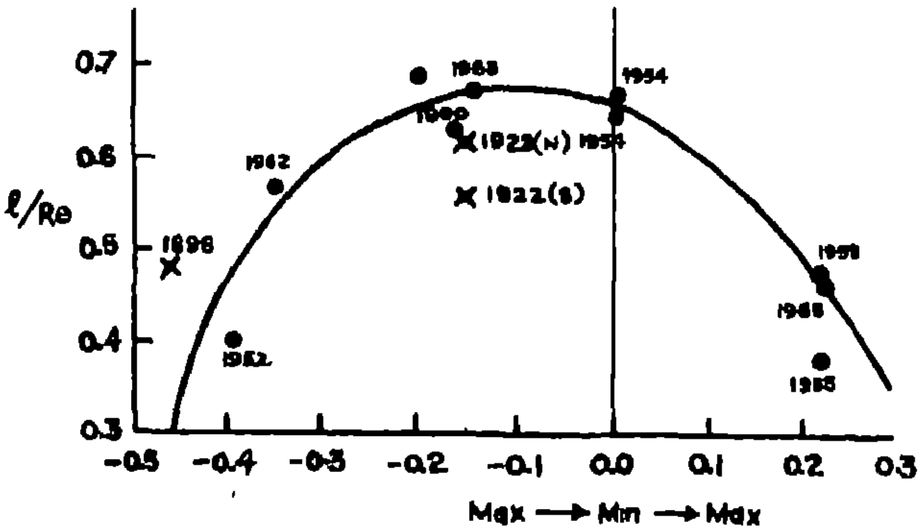


Fig 5.

The length of the hypothetical bar magnet as obtained in the case of the 1898 and 1922 eclipses show variation with the phase of the solar active cycle. We have plotted in Figure 5, the corresponding length of the magnet for these eclipses on Saito's curve showing the variation of length of the hypothetical magnet with the phase of the solar cycle.

**Variation of parameter k with distance from the solar limb**

Several authors have made detailed study of the variation of parameter k with distance from the sun. Waldmeier (1965) has shown for the 1962 eclipse that k is independent of r, while Bachman (1957) and Ivancuk (1964) have observed that k decreases with increasing distance r, for 1954 eclipse. Kopecky and Suda (1966) have made a detailed study of the variation of k with r for several eclipses and could not arrive at any definite conclusion on the dependence of k on r.

Our results obtained from the two eclipses show a variation of k with r near the sun's limb but at large distances k becomes nearly constant with r.

The authors are indebted to Dr M. K. V. Bappu for his helpful suggestions and to the Director of the Lick Observatory for generously making available the Lick Observatory eclipse photographs. Thanks are due to Mr. V. Natarajan for his help during the investigation.

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TABLE 1

*Frequency distribution of Polar rays*

| Eclipse of | Distance from the centre | | 0°—5° | 5°—10° | 10°—15° | 15°—20° | 20°—25° | 25°—30° |
|---|---|---|---|---|---|---|---|---|
| 1898 | $r = 1 \cdot 0\ R_{\odot}$ | NPR | 3 | 4 | 4 | 3 | 3 | 2 |
| | | SPR | 3 | 4 | 5 | 3 | 3 | 3 |
| | | Total | 6 | 8 | 9 | 6 | 6 | 3 |
| 1922 | $r = 1 \cdot 0\ R_{\odot}$ | NPR | 3 | 6 | 4 | 2 | 3 | |
| | | SPR | 3 | 2 | 1 | 1 | 1 | |
| | | Total | 6 | 8 | 5 | 3 | 5 | |

TABLE 2 a

*Apparent angle of obliquity Ψ and polar angle φ for the north polar region in 1898 eclipse plate.*

| No. of P. R. | r=1·0 R | | r=1·1 R | | r=1·2 R | | r=1·3 R | | r=1·4 R | | r=1·5 R | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ |
| 1 | −15·0 | −28·0 | −30·0 | −30·0 | | | | | | | | |
| 2 | −17·0 | −25·5 | −27·0 | −28·0 | | | | | | | | |
| 3 | −18·5 | −24·0 | −24·0 | −26·5 | | | | | | | | |
| 4 | −19·0 | −20·5 | −24·5 | −24·0 | | | | | | | | |
| 5 | −18·0 | −20·0 | −22·0 | −22·0 | | | | | | | | |
| 6 | −14·0 | −18·0 | −21·5 | −20·5 | −34.0 | −22·5 | | | | | | |
| 7 | −15·5 | −14·0 | −20·5 | −16.0 | | | | | | | | |
| 8 | −17.0 | −11·0 | −19·0 | −13·0 | −20.0 | −15·0 | −20·0 | −16·5 | −20·0 | −18·0 | | |
| 9 | −12·5 | − 8·5 | −17·0 | −10·5 | −19·0 | −11·5 | −21·5 | −19·0 | −22·0 | −15·0 | | |
| 10 | − 9·0 | − 6·5 | −19·5 | − 7·5 | −18·0 | − 8·5 | −21·0 | −10·5 | −27·5 | −12·0 | | |
| 11 | − 8·0 | − 4·5 | −14·0 | − 5·5 | | | | | | | | |
| 12 | 10·0 | 1·0 | 1·0 | 0.0 | | | | | | | | |
| 13 | 8·0 | 3.0 | 2·0 | 2·0 | 0·0 | 2.0 | 6·0 | 3·0 | 10·0 | 3·0 | 11·5 | 4·0 |
| 14 | 3·0 | 3·0 | 2·5 | 3.0 | | | | | | | | |
| 15 | 2·5 | 7·0 | 6·0 | 8·0 | 8·0 | 8·5 | 10·5 | 9·0 | 12.0 | 9·5 | 19·0 | 10·5 |
| 16 | 5·0 | 8·5 | 8·5 | 9·0 | | | | | | | | |
| 7 | 5·0 | 9·5 | 9·5 | 10·5 | 14.0 | 11·5 | 15·0 | 12·5 | 15·0 | 14·0 | 14·0 | 15·0 |
| 18 | 12.0 | 10·5 | 17·0 | 12·0 | | | | | | | | |
| 19 | 16·0 | 12·0 | 21·0 | 19·5 | | | | | | | | |
| 20 | 24·0 | 21.0 | 28·0 | 24·0 | | | | | | | | |

Table 2b

*Apparent angle of obliquity* $\Psi$ *and polar angle* $\varpi$ *for South polar region on 1898 eclipse plate*

| No. of P.R. | r=1.0 $R_o$ $\Psi$ | r=1.0 $R_o$ $\phi$ | r=1·1 $R_o$ $\Psi$ | r=1·1 $R_o$ $\phi$ | r=1·2 $R_o$ $\Psi$ | r=1·2 $R_o$ $\phi$ | r=1·3 $R_o$ $\Psi$ | r=1·3 $R_o$ $\phi$ | r=1·4 $R_o$ $\Psi$ | r=1·4 $R_o$ $\phi$ | r=1·5 $R_o$ $\Psi$ | r=1·5 $R_o$ $\phi$ | r=1·6 $R_o$ $\Psi$ | r=1·6 $R_o$ $\phi$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 21·5 | 27.5 | 23.5 | 30·0 | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | 21·5 | 24·5 | 22·0 | 27·5 | | | 18·5 | 33·0 | 19·0 | 34.6 | 22·0 | 36·0 | | |
| 4 | | | | | 15.0 | 28·5 | 17.0 | 30.0 | 18·0 | 31.2 | 20·0 | 32 5 | | |
| 5 | 20·0 | 21.5 | 23·0 | 24.0 | | | | | | | | | | |
| 6 | 20·5 | 20·0 | 26·0 | 22 0 | | | | | | | | | | |
| 7 | | | 20.0 | 20.0 | | | | | | | | | | |
| 8 | 19·0 | 15·5 | 22·5 | 17·0 | | | | | | | | | | |
| 9 | 16·0 | 15·0 | 20.0 | 17.0 | | | | | | | | | | |
| 10 | | | | | | | 10.0 | 11.0 | 6·0 | 16.5 | 6·5 | 17.0 | 10·0 | 17·5 |
| 11 | 20·0 | 13.5 | 11.5 | 15.0 | | | | | | | | | | |
| 12 | 5·0 | 9.0 | 15·0 | 10·0 | | | | | | | | | | |
| 13 | | | | | | | 4.0 | 9.5 | 8 0 | 10.0 | 14·0 | 11·0 | | |
| 14 | | | | | | | 5.0 | 6.2 | 4.5 | 7·0 | 5·0 | 7·5 | | |
| 15 | 1·0 | 1·0 | 2·0 | 1.0 | 3·0 | 1·5 | 5.0 | 1.5 | 9·0 | 2·0 | 15.0 | 3.0 | | |
| 16 | − 3.0 | − 1.5 | − 3·0 | − 2·0 | − 3·0 | − 2 0 | − 2.5 | − 2·5 | − 5 0 | − 2.5 | − 7·0 | − 3·0 | −10 0 | − 3·0 |
| 17 | | | | | − 3.5 | − 4.5 | − 5.0 | − 4.5 | − 9·0 | − 5·5 | −13.5 | − 6·0 | −18·0 | − 7.0 |
| 18 | − 4.0 | − 4.0 | − 6·0 | − 4·5 | − 6·0 | − 5 0 | − 8.0 | − 5.1 | | | | | | |
| 19 | −10·0 | − 5·0 | −11.0 | − 6·5 | | | | | | | | | | |
| 20 | | | | | | | − 6.5 | − 8·5 | − 9·5 | − 9.0 | −13·0 | −10·0 | −25·0 | −11 0 |
| 21 | −12·0 | − 7·0 | −14.3 | − 8·5 | | | | | | | | | | |
| 22 | −16·5 | − 9.0 | −17·0 | −11·0 | | | | | | | | | | |
| 23 | | | | | − 8·0 | −12.5 | −10.5 | −13.5 | −11·0 | −14·5 | −13 0 | −15·5 | −16 5 | −16 0 |
| 24 | −16·0 | −11.5 | −18·0 | −13·0 | | | | | | | | | | |
| 25 | −16·0 | −13·0 | −15·0 | −15·0 | −15·0 | −16.5 | −13.5 | −17.5 | −14.0 | −18·5 | −17·5 | −19·5 | | |
| 26 | −15·0 | −16·0 | −20·0 | −17·0 | | | | | | | | | | |
| 27 | | | | | −14·0 | −21.0 | −19 5 | −22.0 | −23·0 | −24·0 | −28·5 | −26.0 | | |
| 28 | −20·0 | −23·5 | −21.0 | −25·5 | −24.0 | −27 5 | −26.5 | −29·5 | −30·5 | −32.0 | −39.0 | −34 5 | | |
| 29 | −19·5 | −24.5 | −20.0 | −27·0 | −23.5 | −29.0 | −28.0 | −31·5 | −35·0 | −34.0 | −41·0 | −37·5 | | |
| 30 | −18·0 | −26·0 | −23.5 | −29.0 | −26 5 | −31.0 | −32.0 | −33.5 | −38.0 | −37.0 | −49.0 | −41·0 | | |

### TABLE 5a

*Apparent polar angle φ and angle of obliquity Ψ of polar rays on 1922 eclipse plate (North polar rays)*

| Ray No | r = 1·0 R | | r = 1·1 R | | r = 1·2 R | | r = 1·3 R | | r = 1·4 R | | r = 1·5 R | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ | Ψ | φ |
| 1 | −32·0 | −24·6 | −35·0 | −28·4 | −33·0 | −32·0 | −41·0 | −35·7 | | | | |
| 2 | −35·0 | −22·2 | −36·0 | −26·2 | −36·5 | −29·7 | −37·5 | −33·0 | | | | |
| 3 | −32·5 | −20·2 | −34·0 | −23·7 | −35·0 | −27·0 | −36·5 | −30·5 | −36·5 | −33·5 | | |
| 4 | −29·0 | −17·5 | −30·0 | −20·5 | −30·5 | −23·4 | −31·5 | −26·0 | −32·5 | −28·5 | | |
| 5 | −21·0 | −14·5 | −22·5 | −16·7 | −24·0 | −18·8 | −25·0 | −21·0 | −27·0 | −23·2 | −20·0 | −25·4 |
| 6 | −19·5 | −12·6 | −20·0 | −14·7 | −21·0 | −16·6 | −22·0 | −18·2 | −23·0 | −20·0 | −14·0 | −21·7 |
| 7 | −11·0 | −11·5 | −14·0 | −12·8 | −15·0 | −14·2 | −16·0 | −15·5 | −17·0 | −16·8 | | |
| 8 | − 8·5 | − 9·6 | −10·0 | −10·5 | −13·0 | −11·6 | −14·5 | −12·7 | −16·0 | −14·0 | | |
| 9 | − 3·5 | − 8·0 | − 6·0 | − 8·8 | −10·0 | − 9·0 | −12·0 | −10·6 | −14·0 | −11·6 | | |
| 10 | − 3·0 | − 5·2 | − 4·5 | − 5·5 | − 6·0 | − 6·0 | − 7·5 | − 6·5 | − 8·5 | − 7·3 | − 5·0 | − 9·0 |
| 11 | − 3·5 | − 1·4 | − 3·0 | − 1·7 | − 2·8 | − 1·7 | − 3·0 | 1·7 | − 2·0 | − 2·0 | − 1·5 | − 1·5 |
| 12 | − 0·0 | 0·5 | 0·5 | 0·7 | 1·0 | 1·0 | 1·5 | 1·0 | 2·0 | 1·1 | 3·0 | 3·0 |
| 13 | 3·0 | 2·6 | 5·0 | 3·0 | 6·5 | 3·5 | 7·0 | 4·0 | 8·5 | 4·5 | 10·0 | 10·0 |
| 14 | 12·0 | 5·7 | 12·5 | 6·7 | 13·0 | 8·0 | 15·0 | 9·2 | 15·6 | 10·0 | | |
| 15 | 14·0 | 8·8 | 14·0 | 10·1 | 14·5 | 11·2 | 15·3 | 12·5 | | | | |
| 16 | 15·5 | 10·0 | 15·0 | 11·5 | 16·2 | 12·6 | 16·0 | 14·2 | | | | |
| 17 | 18.0 | 12·0 | 19·0 | 14·0 | 22·0 | 15·6 | 24·0 | 17·6 | 25·5 | 19·5 | | |
| 18 | 18·0 | 15·6 | 20·0 | 17·5 | 23·5 | 19·5 | 29·0 | 21·5 | 31·5 | 24·2 | | |

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TABLE 3b

*Apparent polar angle ϖ and angle of obliquity Ψ of polar rays on 1922 eclipse plate (South polar rays)*

| Ray No. | r = 1·0 $R_o$ | | r = 1·1 $R_o$ | | r = 1·2 $R_o$ | | r = 1·3 $R_o$ | | r = 1·4 $R_o$ | | r = 1·5 $R_o$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ψ | ϕ | Ψ | ϕ | Ψ | ϕ | Ψ | ϕ | Ψ | ϕ | Ψ | ϕ |
| 1 | | | | | −33·0 | −24·5 | −40·0 | −27·5 | | | | |
| 2 | −15·5 | −18·5 | −21·0 | −20·5 | | | | | | | | |
| 3 | | | | | −16·5 | −20·4 | −28·0 | −21·8 | −36·0 | −24·6 | | |
| 4 | −13·0 | −11·5 | −17·5 | −12·8 | −21·0 | −14·6 | −26·0 | −16·4 | −29·0 | −18·7 | −32·5 | −21·0 |
| 5 | − 8·0 | − 8·5 | −12·0 | − 9·6 | −14·0 | −10·8 | −16·5 | −12·0 | −18·0 | −13·5 | −22·0 | −15·0 |
| 6 | − 8·0 | − 7·2 | −12·0 | − 8·0 | −15·0 | − 9·9 | −18·0 | −10·5 | −19·0 | −12·0 | | |
| 7 | | | | | | | −19·0 | − 7·5 | −23·0 | − 9·4 | | |
| 8 | | | | | | | −14·0 | − 4·5 | −20·0 | − 5·5 | −26·0 | − 7·5 |
| 9 | 0·0 | 0·3 | 0·0 | − 0·3 | − 0·5 | − 0·5 | − 9·0 | − 1·0 | −10·0 | − 1·2 | −17·0 | − 2·0 |
| 10 | 5·0 | 1·5 | 4·5 | 1·7 | 4·5 | 2·0 | 4·0 | 2·2 | 4·0 | 2·9 | 4·0 | 2·6 |
| 11 | 5·5 | 3·4 | 5·5 | 4·2 | 6·5 | 4·6 | 6·5 | 5·0 | 7·0 | 5·7 | | |
| 12 | | | | | | | 10·0 | 10·8 | 11·5 | 11·2 | | |
| 13 | | | | | | | 14·0 | 15·5 | 20·0 | 17·0 | | |
| 14 | | | | | | | 22·5 | 22·2 | 25·0 | 23·0 | | |
| 15 | | | | | 29·0 | 29·5 | 24·5 | 25·5 | 25·0 | 27·6 | | |
| 16 | 31·5 | 22·5 | 29·5 | 25·5 | 28·0 | 28·4 | 27·0 | 30·6 | 25·5 | 32·5 | | |
| 17 | 31·0 | 24·2 | 32·0 | 27·4 | 34·5 | 30·5 | 38·0 | 34·0 | | | | |

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