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THE TWO COMPONENTS OF THE SOLAR ACTIVITY CYCLE AS A CONSEQUENCE OF THE SHOCK TRANSITION MODEL OF THE SOLAR MAGNETIC CYCLE

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ABSTRACT

Justification is given for comparing the consequences of the 'shock transition model' of the solar magnetic cycle with important observed properties of the solar activity cycle without waiting for the basic postulates of the model to be mathematically established. Such a comparison shows that the creation and the evolution of the *two topologically distinct* families of magnetic flux tubes and their different spatial distributions can account for the 'two component nature' of the solar activity cycle and also for the main qualitative differences in the intensity and distribution of activity in the two components.

The model provides for the formation of long lived coronal-hole-like magnetic structures during the declining years of the activity cycle. This might account for the 'third maximum' in the indices of geomagnetic activity.

Key words : solar activity — solar magnetic fields

1. Introduction

In an earlier paper (Gokhale, 1977b) a phenomenological model of the solar magnetic cycle was presented. It was based on the possibility that a 'sudden transition' of an azimuthal magnetoacoustic oscillation near the base of the convection zone (into largescale convective flows) might produce strong, thin electric current sheaths and magnetic flux sheaths near the nodal and antinodal meridian planes. Repetition of such a sudden (shock) transition every ~ 11 year or so was shown to be possible if the resulting convective flows decayed on timescales ~ 5.5 years, *e.g.* as a result of turbulent viscosity.

The basic postulates about the excitation of the magnetoacoustic oscillation and about the occurrence and the nature of the 'shock transition' are yet to be established by magneto-gasdynamical calculations. Owing to the mathematically complicated nature of the problem, progress in testing these basic postulates has been rather slow. On the contrary it has been easier to compare the consequences of the model with important relevant observations. Agreements revealed by such comparisons do not, by themselves, imply that the model is correct in all details. However, if this limitation is borne in mind, the comparison with observations need not be suspended till all the basic postulates are mathematically established. In fact the continued comparsion with observations will always *help* to sort out the strong and the weak aspects of the model. If the weak points call for modification of the basic postulates it will lead to a timely reformulation of the underlying basic physical problems.

In the present paper we show that the two topologically distinct families of flux tubes which might be produced by the 'shock transition' in our model can account for the 'two component nature of the solar activity cycle and also for the important observed properties of the two components.

2. The Two Components of the Solar Activity Cycle and their Important Properties

In a series of papers Gnevyshev (1966, 1977 and references therein) has clearly shown that the 'averaged' 11-year sunspot cycle has *two* maxima given by *two series of sunspots* which are maximal around latitudes ±25° and ±10° respectively. The first series has a large contribution from small and medium spots whereas the second series consists mainly of large spots. Also the first maximum is associated with an *overall* increase of coronal densities and temperatures at *all* latitudes and during the second maximum these parameters *decrease on the average* but *increase in low latitudes*. Solar-terrestrial effects also have two corresponding maxima followed by a third one in which the 27-day recurrent geomagnetic disturbances are most frequent (Hakura, 1974). These observations together with the observed variations of several other parameters (Kuklin, 1976) clearly indicate that the '11 year' cycle of solar activity has *two* components :

I. the first one consists of (a) spots of all possible sizes in latitudes $\lesssim 40°$ and the associated coronal effects, and (b) 'nonspot' coronal effects *all over the Sun*;

II. the second one consists of mainly *large* spots in *small* latitudes (*e.g.* $\lesssim 20°$) and their coronal effects.

3. Summary of the "Shock-Transition Model" of the Solar Magnetic Cycle

3.1 The Magnetic Structures Produced

In the aforementioned phenomenological model (to be called as "shock-transition model"), it is suggested that sometime before the initial minimum phase of each '11 year' cycle an azimuthal magnetoacoustic oscillation in the "base layer" of the convection zone undergoes a 'shock transition'. This transition generates strong thin current sheaths (magnetic "flux rolls") near the nodal meridian planes and packs the pre-existing weak poloidal field into magnetic "flux sheaths" near the antinodal meridian planes (See Figure 1). The "flux sheaths" and the "flux rolls" have magnetic flux $\sim 10^{21} - 10^{22}$ Mx each. They disintegrate to form 'clusters' (or perhaps 'ropes' : *cf.* Piddington, 1975) of thin flux tubes of $\sim 10^{17} - 10^{18}$ Mx, which rise across the convection zone (*cf.* Gokhale, 1977a).

3.2. Production of Activity

After being elongated, mauled (and probably disintegrated into "subclusters") by the differential rotation and the convective turbulence, the clusters formed from the *flux sheaths* and the *'front portions'* of the *flux rolls* yield, for several years, series of "stitches" above the photosphere (*e.g.* as in Babcock, 1969). These "stitches", their motions, throbbings, expansions, explosions and coalescences, (by reconnections and/or by emergence of the intermediate subphotospheric flux tube segments *e.g.* as in Gokhale 1976), will all lead to a variety of phenomena, at and above the photosphere

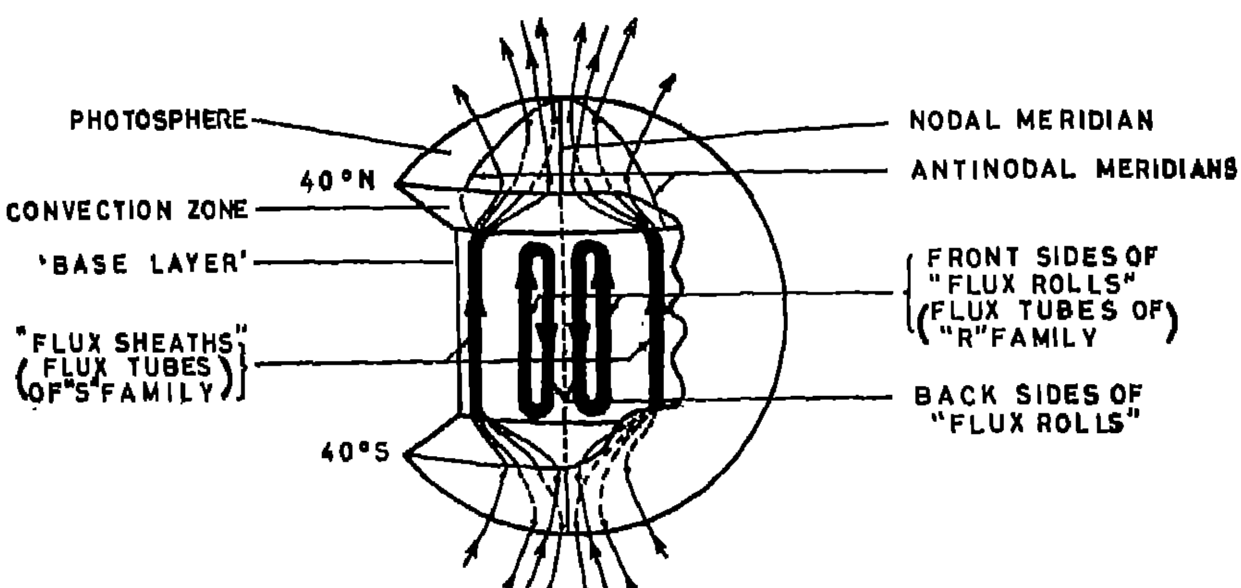

Fig. 1. A schematic diagram illustrating the two topologically distinct types of magnetic structures ("flux sheaths" and "flux rolls") which may be created near the base of the convection zone once in every 11 years or so (presumably when an azimuthal magneto-acoustic oscillation of the Sun undergoes a "shock-transition" cf. Gokhale, 1977b). For simplicity, structures only between two successive antinodal meridian planes are shown. The 'flux sheaths" and the "front portions" of "flux rolls" yield, respectively, the "S" and the "R" families of flux tubes, both of which contribute to the cycle of activity that follows.

which come under the term "activity". In this way the flux tubes formed from each "flux sheath" and from the "front portion" of each "flux roll" will continue to produce activity for several years.

3.3. *The Field Reversal*

Ultimately all the flux tubes in the 'flux sheaths' *go completely above the photosphere and leave the* Sun. This removes the 'old' photospheric fields even from the polar regions. Flux tubes from the 'front portions' of the "flux rolls" also remove their photospheric fields when they go completely above the photosphere. However, at their photospheric intersections which are farthest from the equator they are still connected to the 'back portions' of the flux rolls. These photospheric intersections migrate towards the poles (probably as a result of magnetic tensions in the 'back portions') and disperse by *random walk diffusion. This provides the 'reversed'* photospheric field in the polar regions. In the meanwhile, the 'back portions', which are supposed to be prevented from rising above the base layer, (probably as a result of magnetically channelized mass transfer from the rising 'front portions'), themselves diffuse all over in the "base layer". This provides the *reversed* 'background' field for the *next* shock transition.

3.4. *The Eleven Year Periodicity*

Dissipation of the convective flow produced by a 'shock transition' causes a surplus in the energy budget of the "base layer" which is supposed to excite and amplify a fresh magnetoacoustic oscillation. It has been shown (Gokhale, 1977b) that *if the convective flows dissipate with an 'e^{-1} – folding'* time of $\sim$ 5.5 years, then the new oscillation will reach the 'critical amplitude', and thereby provide the *next* shock-transition, in about $\sim$ 11 years or so. This way the magnetic cycle can repeat with an 'approximate periodicity' of $\sim$ 11 years, the polarity getting reversed from one cycle to the next.

4. The two components of the activity cycle and their essential properties as a consequence of the model

An essential feature of the above model is that each "11-year cycle of activity" has contributions from *two topologically distinct* families of flux tubes ;

i) the flux tubes formed from the breakdown of the "magnetic *flux sheaths*" (which we call the "S" family of flux tubes) and

ii) the flux tubes formed from the breakdown of "flux rolls", in particular their "front portions" (which we call the "R" family of flux tubes).

In terms of these two flux tube families we can account for the two components of the activity cycle and their essential properties as described below.

4.1 *The presence of two maxima in the activity cycle, their chronological order and separation in time*

At the epoch of the shock transition, the 'sub-photospheric high-latitude portions' of the *"S"* family flux tubes are already passing through the main body of the convection zone *above* the "base layer", where convective turbulence and differential rotation are more effective than in the base layer. Therefore, these sub-photospheric portions of the *"S"* family flux tubes will start yielding activity (stitches above the photosphere) *before* other portions of the same flux tubes and flux tubes of the "R" family. Further, while rising, these 'end portions' will exert upward magnetic tensions on the portions in latitudes $\lesssim 40°$ which are in the "base layer" and thereby help the rise of those deeper portions.

In the case of the *"R"* family flux tubes some time will lapse before any of their segments rise to the layers above the base of the convection zone. According to a crude estimate based on existing models of the convection zone, this time lapse may be $\sim$ 1 year or so (Gokhale 1977a) ; and may be more if the "flux rolls" have a lesser tendency to break down than the flux sheaths" (*cf.* sec. 4.2).

Thus the production of activity by the *"R"* family flux tubes will be substantially delayed showing a 'second maximum' 1-2 years after the 'first maximum' corresponding to the peak of the activity produced by the *"S"* family.

4.2. *Relative Spot Sizes and Latitudinal Distributions in the two Components of the Activity Cycle*

Activity produced by the 'S' family flux tubes :

Initially the sub-photospheric high-latitude portions of the 'S' family flux tubes are already scattered *all over* in latitudes $\sim 40^\circ - 90^\circ$ and in *all* longitudes. Moreover, while rising they will also tend to break down the *'S'* family clusters in latitudes $\lesssim 40^\circ$ into 'subclusters' of various smaller amounts of magnetic flux. Therefore, the emergence of the 'S' family flux tubes above the photosphere will yield stitches *all over the Sun*. In successively higher and higher latitudes beyond $\gtrsim 40^\circ$, the stitches of different flux tubes will be more and more isolated from one another, whereas in latitudes $\lesssim 40^\circ$ they will emerge crowded in 'subclusters' of various possible magnetic flux values.

Thus the *'S'* family of flux tubes will produce :

(i) a substantial amount of 'activity' in small *"spotless"* events *at all latitudes* (like; the 'ephemeral active regions' in the photosphere, *cf.* Harvey *et al.* 1975 ; and the X-ray bright points in the corona, *cf.* Golub *et al.* 1977) ; and

(ii) *spots* and 'conventional' active regions of *all kinds* of *sizes* in latitudes $\lesssim 40^\circ$.

Activity produced by the 'R' family flux tubes :

The "flux rolls" are created wholly within the latitudes $\pm 40^\circ$ and their 'front portions', which constitute the *'R'* family flux tubes, will be drawn into much smaller latitudes as a result of winding by the *differential rotation during the rise*. Therefore, the activity produced by the 'R' family flux tubes will be *confined to* latitudes *much less than* 40°.

The 'back portions' of the "flux rolls" remain in the base layer and diffuse much slower than the rising 'front portions'. As a result of this, the magnetic tensions from the back portions will tend to prevent the *'R'* family 'clusters' from breaking down into too small subclusters. Therefore, the *'R'* family 'clusters' will produce *relatively larger* and *relatively more stable* spots.

Thus the qualitative differences between the latitudinal distributions and the size distributions of the activity expected from the *'S'* and the *'R'* families of flux tubes agree well with the observed differences between the distributions corresponding to the first and the second maxima in the activity cycle.

4.3 The Coronal Characteristics of the Two Components

The observed largescale latitudinal homogeneity of the corona with an increase in the coronal density and temperature at *all latitudes* during the *first maximum* can result from the rather homogeneous distribution of stitches formed by the *S* family flux tubes over *all* latitudes. The increase of density and temperature in the low latitudes, the decrease of their overall averages and the resulting largescale inhomogeneity of the corona during the *second maximum* must be because : (a) *'R'* family flux tubes which give the second maximum remain strongly clustered, (b) they yield activity only in the low latitudes, and (c) this activity reaches maximum during the *declining* years of the homogeneously distributed activity given by the 'S' family.

4.4 The Three Maxima in the Geomagnetic Activity Indices and the Relation of the Third Maximum to the long lived Coronal Holes

The first two maxima in the geomagnetic activity indices correspond to the two maxima in the activity cycle and have already been related to the corresponding peaks in the proton flare activity (Gnevyshev, 1977). With the help of the present

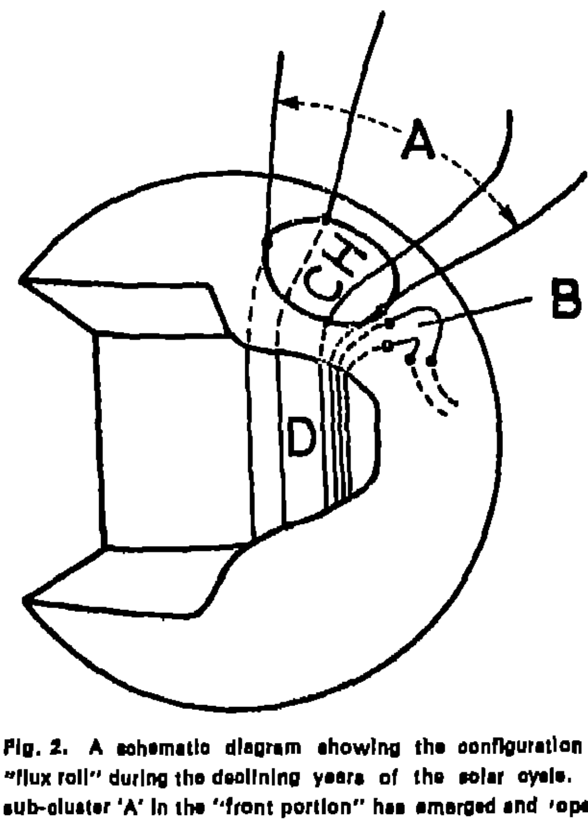

Fig. 2. A schematic diagram showing the configuration of a "flux roll" during the declining years of the solar cycle. The sub-cluster 'A' in the "front portion" has emerged and 'opened out', the sub-cluster 'B' has emerged but has not yet opened out. 'CH' is the largescale monopolar photospheric magnetic cell given by photospheric intersections of flux tubes in the sub-cluster 'A'. 'D' is the 'back portion' of the flux roll. It is in the 'base layer' and is diffusing slowly.

model we can account for the third maximum, which is characterized by the abundance of 27-day recurrent geomagnetic disturbances, in the following manner. During the decay of the second component of the activity cycle, which is given by the '*R*' family of flux tubes, the magnetic tensions from the slowly diffusing back portions of the "flux rolls" will *slow down* the random walk dispersal of those 'subclusters' in the 'front portions', which have already emerged and 'opened out' to the interplanetary space (*e.g.* "A" in Fig. 2). This will provide photospheric field regions whose 'monopolar' character on largescale is rather long lived and whose field lines are 'open' above the photosphere and reach large depths (in fact the "base layer") in the convection zone: essentially the magnetic configurations of the coronal holes (*cf.* Levine, 1977, Krieger, 1977). If '*R*' clusters in such phases do produce long lived coronal holes in the said manner then the abundance of the 27-day recurrent geomagnetic disturbances after the second maximum (essentially the 'third peak' in the geomagnetic activity indices) can be understood as a consequence of the fast streams associated with the coronal holes (Bohlin and Hulbert 1977), whatever be the mechanism for the creation of such fast streams.

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