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SHORT PAPER

THE 22-YEAR SOLAR CYCLE: A HELIOSPHERIC OSCILLATION?

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Abstract

A new mechanism is proposed for the origin of the 22-year solar cycle in which the solar cycle is caused by a large scale oscillation of the heliosphere. In its simplest terms the oscillation is directly analogous to an LC oscillator, with the heliospheric current system providing the inductance, and accumulated charge near the heliosphere boundary providing the capacitance. Estimates of the oscillation period using reasonable parameters are close to 22 years.

Of the many problems of solar physics, few can be regarded as fundamental as understanding the cause of the 22-year solar cycle. During the seventy years since the discovery of the 22-year cycle governing the magnetism of sunspots (Hale, 1913) numerous mechanisms have been proposed to account for the observed periodicity. For example, in an early model, Bjerkness (1926) proposed that sunspots are analogous to terrestrial tornadoes and that a large scale circulation interior to the sun alternately brings oppositely directed vortices to the surface on a 22-year cycle. Walen (1946) suggested that the solar cycle is caused by a torsional magnetohydrodynamic oscillation of the sun which is excited by convulsions of unknown origin within the sun. Later, Alfvén, (1948) proposed that successive reflection of Alfvén waves (whirl rings) propagating between the northern and southern hemispheres of the sun accounted for the periodicity. All of these models have encountered serious difficulties. For a critical review see Cowling (1953).

More recent efforts to explain the solar cycle have focused on the dynamo mechanism first described in detail by Babcock (1961). This model involved four stages in the 11-year half cycle, consisting of an initial dipolar field, the stretching of the dipolar field into a toroidal field by differential rotation, the formation of bipolar magnetic field regions and sunspots using Parker's (1955) magnetic buoyancy mechanism and the neutralization and reversal of the initial dipolar field by reconnection. Babcock's model has since been further refined and analyzed by numerous investigators, including for example Leighton (1969) and Yoshimura (1975). Although the current dynamo models can account for many of the detailed solar cycle characteristics, these models all involve numerous internal parameters of the sun which cannot be directly verified. Also, the mechanism for reversing the initial dipolar field is not entirely understood.

Up to the present time all of the proposed solar cycle mechanisms involve processes interior to the sun. We would now like to suggest an entirely new mechanism in which the solar cycle is caused by a large scale magnetohydrodynamic oscillation exterior to the sun, in the region known as the heliosphere. In its simplest terms the oscillation is directly analogous to an LC oscillator, with the heliospheric current system providing the inductance, and the accumulated charge near the heliosphere boundary providing the capacitance. As will be shown, estimates of the oscillation period using reasonable parameters are close to 22 years.

As defined by Dessler (1967), the heliosphere is the region around the sun which is dominated by the supersonic solar wind flow outward from the sun. Best estimates now place the boundary between the heliosphere and the interstellar medium at about 50 AU (Axford *et al.*, 1963; Brandt, 1970). Spacecraft measurements (Smith *et al.*, 1978) show that the magnetic fields within the heliosphere are oppositely directed in the northern and southern hemispheres and are wound up in Archimedean spirals by the solar rotation as shown in Fig. 1. The magnetic fields in the two hemispheres are separated by an equatorial current sheet. To avoid a large charge build-up at the sun, the outward directed current near the equatorial

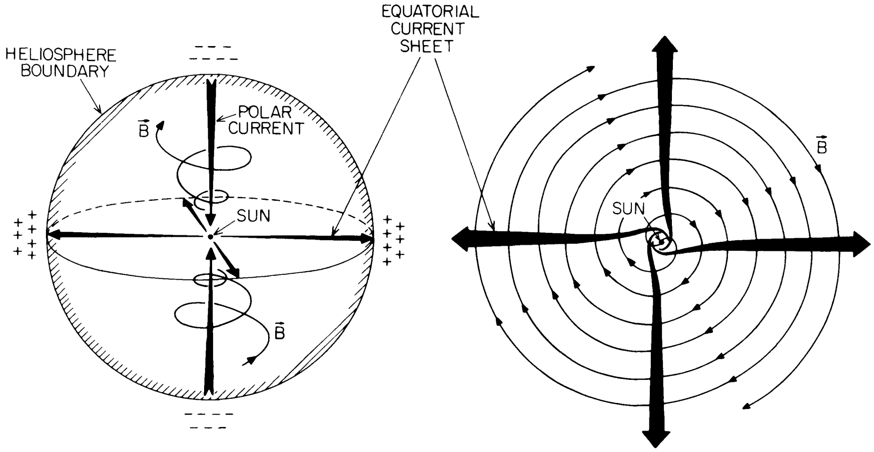

Fig. 1. "SIDE" AND "TOP" VIEWS OF THE MAGNETIC FIELD AND CURRENT SYSTEM IN THE HELIOSPHERE. The outward flow of the solar wind plasma and the solar rotation cause the magnetic field to be twisted around the sun in an Archimedean spiral. The magnetic fields in the northern and southern hemispheres are in opposite directions and are separated by an equatorial current sheet flowing outward away from the sun. This current is compensated by an equal and opposite inward current over the two polar regions. The currents and magnetic fields reverse directions twice during each 22-year solar cycle.

plane must be compensated by an inward directed current over the polar regions (Alfvén, 1977) as shown in Fig. 1. Since the polar magnetic field of the sun reverses polarity every 11 years, the direction of the magnetic field and current systems must reverse every half cycle. This implies that magnetic energy must be stored and released during each half cycle. The energy storage can be represented by an equivalent inductance, L, associated with the current system. Using the magnetic field model of Parker (1958) it can be shown that the equation for the inductance is

$$L = \frac{\mu_o}{4\pi} R_H \left[\frac{2}{3} + \frac{R_o^2}{R_s R_H}\right], \tag{1}$$

where R_H is the radius of the heliosphere, R_s is the source surface radius (Hundhausen, 1972) and R_o is the radius at which the spiral angle of the magnetic field is 45°. For nominal parameters, R_s = 2.0 solar radii, R_o = 1 AU, and R_H = 50 AU, the inductance given by Eq. (1) is $L \simeq 2.1 \times 10^6$ Henrys.

We now turn our attention to the possible location for a capacitance associated with this current system. Since the polar current system connects to the equatorial current system through the highly conducting lower levels of the solar corona, a large charge accumulation is not expected near the sun. A more likely location for a charge accumulation is near the heliosphere boundary, as indicated in Fig. 1. The equivalent circuit of the system would then have the form of an LC oscillator as shown in Fig. 2. Although no direct evidence exists for a charge accumulation at the heliosphere boundary, several arguments can be presented which support this conjecture. First, since all of the magnetic field lines from the northern hemisphere must ultimately connect to the southern hemisphere, any current from the equatorial to polar regions must flow across the magnetic field lines. Since the

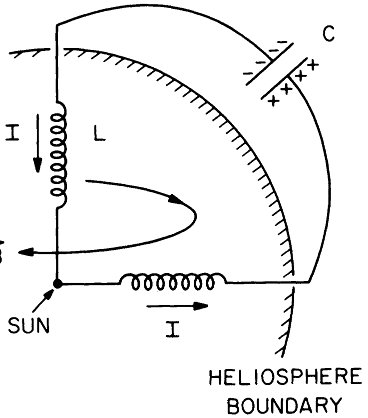

Fig. 2. AN LC CIRCUIT ANALOG OF THE CURRENT AND CHARGE SYSTEM ILLUSTRATED IN FIG. 1. L is the equivalent inductance associated with the magnetic energy storage in the heliosphere, and C is the equivalent capacitance associated with the electric field and plasma energy storage outside the heliosphere. This model predicts an oscillation of the currents and fields with a period of $T = 2\pi\sqrt{LC}$. Estimates of the LC oscillation period predicted by this model are in good agreement with the 22-year period of the solar cycle.

collision frequency of the plasma in this region is very small, it is readily shown that the conductivity across the magnetic field is essentially negligible. Also, it can be shown that the pressure gradient at the heliosphere boundary is too small to provide significant diamagnetic currents across the magnetic field. For example, from $\vec{J} \times \vec{B} = \vec{\nabla} p$ it can be shown that the diamagnetic current per unit length is $I_\ell = \Delta p/B$, where Δp is the pressure difference across the current layer. For typical interstellar plasma parameters, $n = 0.025$ protons cm^{-3}, $T = 100°$ k, and $B = 0.7$ gamma (Chandrasekar and Fermi, 1953; Weisberg, 1978), with $(\Delta p)_{\max} = nkT$, the maximum diamagnetic current is $(I_\ell)_{\max} \simeq 4.5 \times 10^{-8}$ amp m^{-1}. This current is small compared to the equatorial current density of about 1.4×10^{-4} amp m^{-1} which must flow from the equator to the poles in order to close the current loop. The basic magnetic field geometry therefore provides a very effective insulator between the equatorial and polar regions. Second, although in steady state it would be possible for the polar and equatorial current systems to extend outward to infinity, because of the low propagation velocity (~ 50 km/sec) in the interstellar plasma, the radial extent of the current system is limited to only a few times the radius of the heliosphere during one solar cycle. Since the current system must reverse direction at least twice during each solar cycle and cannot flow across the magnetic field, the requirement for charge accumulation somewhere near the heliosphere boundary seems inescapable. Since the heliosphere boundary provides a transition region between the solar and interstellar magnetic fields, it seems most likely that any charge accumulation should occur in this region. The situation would then be somewhat comparable to the earth's magnetopause, where polarization charges are known to be produced by the interaction between the terrestrial magnetic field and the solar wind.

Given that charges of opposite sign do accumulate near the equatorial and polar regions of the heliosphere boundary, electric fields would be produced in the interstellar medium and the transition region. The energy stored in these electric fields and the resulting $\vec{E} \times \vec{B}$ motions of the plasma in the interstellar magnetic field, can be represented by a capacitance C. From fairly general scaling relationships it can be shown that the capacitance is essentially equivalent to that for a spherical capacitor of radius R_H

$$C = \alpha K(4\pi\varepsilon_o R_H), \tag{2}$$

where α is a constant of order 1 which corrects for the deviation from a spherical geometry and K is the plasma dielectric constant. For a magnetized plasma the dielectric constant is given by

$$K = \frac{c^2}{V_A} = \frac{\mu_o c^2 \rho}{B^2}, \tag{3}$$

where V_A is the Alfvén velocity, c is the speed of light, B is the magnetic field strength and ρ is the mass density. For the best current estimates of the interstellar plasma density, 0.025 protons cm^{-3}, and interstellar magnetic field strength, 0.7 gammas (Weisberg, 1978; Chandrasekar and Fermi, 1953), in the general vicinity of the heliosphere boundary, the dielectric constant is estimated to be 9.7×10^6. For $\alpha = 1$ and $R_H = 50$ AU the corresponding capacitance is $C = 8.0 \times 10^9$ farads. Using the previously computed inductance, the resulting oscillation period is then

$$T = 2\pi\sqrt{LC} = 8.1 \times 10^8 \text{ sec} = 25.8 \text{ years}. \qquad (4)$$

This period is somewhat longer than the 22-year solar cycle, but still in remarkably good agreement. Table 1 summarizes the oscillation period computed for a range of heliospheric radii and interstellar parameters which are considered to be within an acceptable range. One case is also computed using the asymptotic solar wind density and magnetic field strength, which would be characteristic of the transition region between the heliosphere and the interstellar medium. In all cases the oscillation period is within a factor of 2 to 3 of 22 years.

TABLE 1

R_H AU	R_S Solar Radii	n cm^{-3}	B gamma	$T(\alpha = 1)$ Years	$T(\alpha = 0,3)$ Years
50	2.0	0.025	0.7	25.8	14.1
100	2.0	0.025	0.7	40.8	22.3
50	2.0	0.1	0.7	51.6	28.3
50	2.0	0.01	0.7	16.4	8.9
50	2.0	0.025	1.0	18.1	9.9
50	2.0	0.025	0.3	60.5	33.2
50	2.5	0.025	0.7	23.9	13.1
50	2.0	0.002*	0.1*	51.3	28.1

* Asymptotic Solar Wind Parameters Extrapolated from 1 AU.

Because of the obvious uncertainties in the plasma parameters and geometric details of the model, close agreement with the actual period of the solar cycle is not expected. The main point of this calculation is to determine whether the first order oscillation period of the heliosphere is even remotely close to the actual period of the solar cycle. In fact, the computed period from the model is quite close to the observed oscillation period. To our knowledge no other model provides a comparable direct estimate of the period with better accuracy. The various solar dynamo models, for example, all involve various unknown internal parameters of the sun which are usually determined by requiring that the oscillation period be 22 years (see, for example, Leighton, 1969; Yoshimura, 1975).

It may be, of course, that the good agreement between the computed and actual oscillation period is simply a numerical coincidence and that the model has no physical content. Several aspects of the model are in fact questionable. The requirement that the charge accumulate near the heliosphere boundary is a basic assumption which remains unproven. Furthermore, this assumption violates a well-known requirement of magnetohydrodynamics, namely that $\vec{\nabla} \cdot \vec{J} = 0$. The basic picture in which the heliospheric current loop is regarded as an electrical circuit also violates conventional ideas involving magnetohydrodynamics since there is no way for information to propagate back toward the sun against the supersonic solar wind flow. These conflicts with conventional magnetohydrodynamics do not, however, render the basic model invalid since numerous examples are now known where magnetohydrodynamics fails to account for all of the observed effects in a large scale plasma. It is now reasonably well accepted, for example, that substantial charge accumulations and parallel electric fields occur along the earth's auroral field lines,and that electrons in the solar wind can control the electrostatic potential distribution in the solar wind, even though the solar wind speed is supersonic. The heliospheric oscillation model also does not address the ultimate energy source of the oscillations. Our feeling on this subject is that if a basic mode of oscillation can be identified, then numerous possibilities probably exist for exciting the oscillation.

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