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PLASMA PHYSICAL ASPECTS OF THE SOLAR CYCLE

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PLASMA PHYSICAL ASPECTS OF THE SOLAR CYCLE

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Abstract. Mass motions below the photosphere drive the solar cycle which is associated with variations in the magnetic field structure and accompanying phenomena. In addition to semi-empirical models, dynamo theories have been used to explain the solar cycle. The emergence of magnetic field generated by these mechanisms and its expansion into the corona involves many plasma physical processes. Magnetic buoyancy aids the expulsion of magnetic flux. The corona may respond dynamically or by continually adjusting to a quasi-static force-free or pressure-balanced equilibrium. The formation and disruption of current sheets is significant for the overall structure of the coronal magnetic field and the physics of quiescent prominences. The corona has a fine structure consisting of mangetic loops. The structure and stability of these are important as they are one of the underlying elements which make up the corona.

1. Introduction

It may be argued that the most fundamental aspect of the solar cycle is revealed in the recurring pattern of magnetic field variations. Certainly the first evidence of the cyclical nature of solar activity was found from sunspot observations, and the magnetic polarity of sunspots was subsequently shown to be closely correlated to the phase of activity. A basic problem which is of current interest is the driving mechanism of the solar cycle. As regards the magnetic activity, explanations are sought for the origin, maintenance and regular variation of the large-scale field. Dynamo theory is one promising line of approach, where the combined effects of sub-photospheric convection, Coriolis forces and differential rotation are taken into account.

In Babcock's (1961) theory of the solar cycle differential rotation builds up a strong sub-photospheric azimuthal field from the poloidal magnetic field. This field rises to the surface to form sunspots where as a natural consequence the leading spots in a given hemisphere have the same polarity. There is a systematic difference between the latitude of a leading spot and those following so that as the field is dispersed as a result of sunspot decay there is a feedback to the original poloidal field. Leighton (1969) has developed a quantitative semi-empirical model including turbulent diffusion of magnetic field as a random walk process. An alternative approach has been to apply dynamo theories and in particular the α-effect dynamo based on mean field electrodynamics (Parker, 1955b; Steenbeck et al., 1966; Steenbeck and Krause, 1966; Roberts and Stix, 1972). The basic concept is that cyclonic turbulence leads to the induction of an average current parallel to the average magnetic field. This will for example provide a feedback from an azimuthal field to the poloidal field component. The application to the solar cycle is treated for example by Deinzer and Stix (1971) and Stix (1976). Non-linear effects are important in limiting the growth of the field (Stix, 1972; Schüssler, 1979b).

Of equal interest are what may be termed accompanying mechanisms of the solar cycle. By this is meant those processes which are in turn driven by the general variations of the solar magnetic field.

The structure of the corona, for example, follows these variations of the general magnetic field during the solar cycle. During the cycle both the structure of the magnetic field and the amount of flux penetrating the corona vary. The way in which the coronal plasma responds to these variations gives rise to a variety of phenomena, such as the formation of prominences, coronal holes, loops and transients. Energy may also be stored magnetically to be released in solar flares, disparitions brusques and other eruptive events. All of these phenomena may be regarded as consequences of accompanying mechanisms of the solar cycle, such as the emergence of magnetic flux, the formation of current sheets and the induction of electrical currents in the corona.

Many of the mechanisms which have been invoked in theories of solar phenomena involve plasma physics and may be compared with laboratory experiments and the results of fusion research (see for example Spicer, 1982). Magnetohydrodynamic equilibrium and stability are central problems of plasma physics, and concepts such as pinching, kink and interchange modes have found application in solar physics. Anomalous transport properties, e.g. resistivity, were first studied in connection with fusion research. These are a consequence of plasma turbulence due to the growth of unstable electrostatic plasma modes. Large amplitude electrostatic phenomena such as double layers (cf. Torvén, 1979) have similar consequences to plasma turbulence and may lead to alternative ways of releasing magnetic energy in solar flares (Carlqvist, 1968) and as mass motions in surges (Carlqvist, 1979). Double layers may also form as a result of the non-linear development of electrostatic instabilites (Raadu and Carlqvist, 1981). Discussions of mechanisms for solar radio bursts rely heavily on results from plasma physics. Thus it is worthwhile to keep in mind the plasma physical aspects, often implicit, of solar activity.

2. Magnetic Flux Emergence

Jensen (1955) and Parker (1955a) independently proposed that magnetic flux tubes within the solar interior should rise to the surface as a consequence of magnetic buoyancy. This is a consequence of the reduced density within a flux tube in thermal equilibrium with its surroundings, given that the external pressure is partly balanced by the magnetic pressure within the flux tube so that the internal pressure is reduced (see Figure 1). Gilman (1970) considered a plane-parallel gas in a gravitational field with a horizontal magnetic field and showed the existence of unstable buoyancy modes in the form of long thin applifying magnetic loops.

The dynamics of buoyant thin magnetic flux tubes has been investigated by Schüssler (1977, 1979a) He includes the braking effects of aerodynamic drag and viscous forces as considered by Pneuman and Raadu (1972). Typical vertical velocities are then a few meters per second, sufficient to rise through the convection zone on the time scale of the solar cycle. Schüssler (1979b) also looks at the problem of non-linear effects on α--effect dynamos (cf. review of Stix, 1976) and concludes that buoyancy effects may limit the magnetic field but do not inhibit the dynamo action (cf. Parker, 1977). Recently Spruit (1981) has derived general equations of motion for thin untwisted flux tubes in the convection zone and in particular found a force component due to buoyancy perpendicular to the axis.

In addition to these effects convective motions should be important in bringing magnetic flux up to the photosphere. The large scale pattern of upward flux transport should be influenced by the form of large-sclae convection cells, giant cells, in the solar atmosphere. However the observational evidence for these has been difficult to find (La Bonte et al., 1981). Meyer et al. (1979) have calculated the combined effects of buoyancy and convection for flux tubes in a supergranular cell and also apply their results with the emergence of active regions. They find that a tube emerges in the centre of a cell and that buoyancy causes a rapid migration of the foot points to the cell boundaries.

3. Expansion of Magnetic Fields into the Corona

The emergence of magnetic fields through the photosphere and chromosphere out into the corona is complicated by a number of factors. The photospheric field is concentrated into flux elements of only a few hundred kilometers diameter (Stenflo, 1976) with field strengths of a few thousand gauss, presumably as a consequence of small scale convective motions seen as granules and supergranules (Galloway et al., 1977). The consequences of this highly non-uniform structure have still not been fully incorperated in analyses of the outward expansion of magnetic fields. The expansion carries emerging flux through a rapidly changing medium, with falling density and greatly increasing temperature and ionization degree. Theoretical analyses consequently require considerable simplification both as regards modelling and physics.

Magnetic buoyancy effects are also relevant to magnetic flux expansion in the corona. Low et al. (1982) argue that there is a class of coronal transients which are not initiated impulsively but are the result of a quasi-static response to photospheric field development. They interpret observations of an expanding arch system with reduced density in terms of a model for the static equilibrium of a bipolar magnetic field region embedded in a gravitationally stratified non-magnetized plasma (Low, 1981). In equilibrium the magnetic pressure at the top of the arches is determined essentially by the height and the contained flux, whereas the external plasma pressure is already prescribed (see Figure 1). If these two distinctly determined pressures cannot be made equal no equilibrium is possible and a dynamic state results. Parker (1979) came to similar conclusions for the case of an isolated flux tube. The driving force is the buoyancy of the magnetic field region. Equating the magnetic pressure to the dynamic pressure of matter driven upwards by the expansion Low et al. (1982) derive a constant expansion velocity comparable with observed values.

Nakagawa et al. (1976) have treated the emergence of magnetic arches into the lower corona numerically representing the plasma as a single infinitely conducting fluid. For rates of flux increase (7×10^8 Weber s^{-1}) typical for flare associated changes they find that, in the case of strong magnetic field, an upward propagating shock is created and plasma flows upwards in the centre of the loops. Supersonic downflow of cool tenuous plasma is found at the feet of the arches. For less rapid rates of flux emergence one would expect to find a series of quasistatic configurations, corresponding to the continuously varying boundary conditions. In general the emerging flux may have a sheared or twisted structure so that, for example, in the limit of very low plasma density a force-free configuration with currents flowing parallel to the magnetic field must be set up (Nakagawa et al., 1971; Nakagawa et al., 1973;Chiu and Hilton, 1977; Seehafer and Staude, 1979; Alissandrakis, 1981; Sakurai, 1981).

The search for force-free solutions of the coronal magnetic field has been complicated by the general non-linear nature of the problem. In particular multiple solutions may arise for given boundary conditions as discussed by Jockers (1976, 1978) and Low (1977). Jockers (1978) has found a sequence of solutions for sheared magnetic arches, where a varying current distribution is specified. For given conditions two solutions are found which finally merge at a critical point beyond which no equilibrium can be found. For one branch closed field lines may be formed above the photosphere (magnetic islands). Such structures may be suppressed by suitable restrictions on the current distribution. However two branches still occur for one of which the field lines rise higher into the corona. Jockers (1978) emphasizes that on physical grounds it would be preferable to specify the photospheric shear rather than the current distribution. The results are however of immediate significance for attempts to calculate field structures on the basis of measured photospheric current and field distributions.

Syrovatskii (1978) has argued that for an adiabatic approximation the problem of the continuous deformation of a force-free field has in general no solution. Small changes in the boundary conditions may then lead to large scale changes in the field structure. A further consequence is that current sheets may be formed. These arguments together with the results of Jockers (1976, 1978) and Low (1977) indicate the complexities that may result from the seemingly simple hypothesis of force-free conditions. Heyvaerts et al.(1979) present a detailed survey. Also they find that with suitable restrictions equilibrium solutions are possible, but thresholds exist beyond which dynamic evolution should occur.

Photospheric motions may also be expected to lead to a continued modification of the coronal magnetic field. Thus, twisting and shearing may be expected to set up force-free currents along field lines. On a large-scale the solar differential rotation will induce an extended current system which increases continuously leading to an outward expansion of magnetic fields (Raadu, 1972b). Parker (1981a and b) has considered the effects of flux tube dislocations as a result of photospheric motions or inflation due to lack of pressure equilibrium. Such flux tubes tend to be flattened by the ambient field lines leading to enhanced dissipative effects releasing the stored energy. This should contribute to coronal heating and incidentally allow the developing field structure to remain close to a current-free configuration.

4. Current Sheets

The effective electrical conductivity of the solar corona is so high that the field structure resulting from flux emergence cannot immediately relax to a current-free state. Current sheets may be expected separating newly emerged from pre-existing magnetic fields, so that initially there are no interconnecting field lines (see Figure 1). Green (1965) showed how such a neutral sheet will form between two approaching line currents. More recently Priest and Raadu (1975) used a similar method to show the formation of a current sheet between line dipoles. In principle comparable results follow from approaching constant sources and increasing sources e.g. contiguous emerging flux regions. The development and subsequent disruption of such current sheets has been considered as a possible mechanism for solar flares (Syrovatskii, 1970, 1977; Heyvaerts et al., 1977). Somov and Syrovatskii (1980) argue that plasma ejections on the perifery of developing spots can result from the break up of a current sheet.

Kuperus and Tandberg-Hansen (1967) presented a model for the formation of quiescent prominences in a coronal current sheet. Such sheets may form as a result of flare activity breaking open overlying magnetic arches. The tearing mode (Furth et al., 1963), modified by thermal instabilities, should then lead to the formation of current filaments comparable in size to observed small structures. Raadu and Kuperus (1973; Kuperus and Raadu, 1974) developed this model showing how photospheric boundary conditions favour the formation of thin prominence sheets and allow the support of current filaments. They argued that prominences should form in current sheets lying between distinct regions of flux emergence. Giant cells may play a role in bringing matter into the prominence, favouring reformation after disparition brusque. Quiscent prominences should then overly regions of downward photospheric motion where coronal magnetic field is convected downwards as part of the solar cycle mechanism (Raadu, 1978).

It is apparent that current sheet behaviour is of central interest for the devlopment of coronal magnetic fields and hence even for that part of the solar cycle mechanism that depends on this development. Uchida and Sakurai (1977) note that observations (Sheeley et al., 1974) indicate that connections may be established between distant distinct polarity regions without any appreciable flare or other energetic activity. One may note here the reasonably good predictions of coronal structure that may be obtained from current-free field configurations (Altschuler and Newkirk, 1969; Schatten, 1971; Altschuler et al., 1977). Uchida and Sakurai (1977) show that interchange instabilities can lead to the interpenetration of magnetic fields from distinct flux regions on a short, hydromagnetic time scale, leading to an enhanced dissipation of current sheets lying at the interface. This can explain the fast reconnection of fields without appreciable flares.

Recent detailed laboratory studies of Stenzel et al. (1980) can help to illuminate the physics of current sheets. Their experiments are designed to diagnose reconnection processes at an x-type neutral line. The currents producing the magnetic field are time-dependent, so that current sheets are induced in such a way as to try to maintain the separation of distinct flux regions, as has been argued for the corona. For increasing field strength a stable current sheet is seen; but for decreasing field break up into current filaments as a result of tearing mode instabilities (Furth et al., 1963) is observed (see also Stenzel and Gekelman, 1981), Closely related work on the plasma physics in the neighbourhood of neutral lines was also carried out for example by Bratenahl and coworkers (Bratenahl and Yeates, 1970; Baum and Bratenahl, 1977) and Syrovatskii et al.(1972) .

It is of interest to note that the physics of current sheets is important not only for the large scale structure of the corona and the formation of quiescent prominences, but also in the context of solar flare theory. Current sheet models of solar flares have, for example, been developed by Heyvaerts et al. (1977), Tur and Priest (1978) and Heyvaerts and Kuperus (1978). Anomalous resistivity as a result of current driven instabilities is an important feature of these models. It is then worth noting that Wild et al. (1981) found an anomalous resistivity that does not maximize in the regions of largest current. Also, lower--hybrid-drift instabilities can lead to an anomalous resistivity (Huba et al., 1977) in the outer regions of current sheets for sufficiently sharp density gradients (cf. Papadopoulos, 1979). It is important to identify the actual driving instability in order to find the critical conditions for onset, the distribution of anomalous Joule heating and the saturation mechanism. If heating is restricted to the outer edges a cool prominence may coexist with anomalous energy release.

5. Coronal Loops

The solar corona has a detailed fine structure consisting of magnetic loops both inside and outside active regions. This structure is clearly shown by X-ray observations which reveal loops which range is size from those which are just resolved, a few thousand kilometers, to those stretching over the disc even connecting separated active regions (Vaiana et al., 1976; Vaiana, 1976). EUV observations indicate the presence of very cool matter (Foukal, 1975, 1976). The thermal properties of coronal loops are still not fully understood (Raymond and Foukal, 1982) and this may in part be due to our incomplete knowledge of coronal heating mechanisms. Ionson (1982) has considered resonant electrodynamic heating processes in coronal loops and introduced an LRC circuit analogue. Craig and McClymont (1981) argue that radiative instabilities in loops have a very slow growth rate , in contradiction to previous results (e.g. Hood & Priest, 1979b), if the effects of thermally stable chromospheric material at the base are included.

Current carrying loops with a twisted magnetic field structure are liable to be unstable to kink instabilities. Anzer (1968) considered this problem in the context of energy storage for solar flares and Raadu (1972a) showed that photospheric line tying can stabilize a twisted flux rope if the degree of twisting is moderate. Their analyses were based on Newcomb's (1960) method of examining second order energy perturbations. From observations of flare emissions in the XUV wavelength region Cheng (1977) found evidence for disruption of a loop by the kink instability. Hood and Priest (1979a) include the effects of pressure gradients which may also be stabilizing. They conclude that this is important for the persistence of coronal loops and that in case of instability eruption of active region filaments may occur. Van Hoven et al. (1981) have further generalized the class of perturbations used to test stability and confirm previous results.

Under suitable conditions currents can drive an outward expansion of a coronal loop. Anzer (1978) has presented a dynamical model of an expanding loop as a model for coronal loop transients which may be compared with that of Mouschovias and Poland (1978). Carlqvist and Alfvén (1980) argue that the kinetic energy of an expanding loop contributes to the solar wind energy and that electrical power may be fed continously into extended loops.

6. Conclusions

One of the proposes of this review has been to emphasise the intimate relation between the solar magnetic cycle and a series of active phenomena. The connecting link is provided by the progressive outward transport of mangetic fields from the convection zone where the presumed primary driving mechanism of the solar cycle is operating. At the same time it has been stressed that many of the underlying processes involve plasma physics, and indeed many of the concepts where first developed in the fields of fusion and pure plasma physics. One may look forward to further transfer of knowledge which hopefully will be in both directions.

7. Acknowledgements

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References

Alissandrakis, C.E.: 1981, Astron. Astrophys. 100, 197.

Altschuler, M.D. and Newkirk, G.Jr.: 1969, Solar Phys. 9, 131.

Altschuler, M.D., Levine, R.H., Stix, M. and Harvey, J.: 1977, Solar Phys. 51, 345.

Anzer, U.: 1968, Solar Phys. 3, 298.

Anzer, U.: 1978, Solar Phys. 57, 111.

Babcock, H.W.: 1961; Astrophys. J. 133, 572.

Baum, P.J. and Bratenahl, A.: 1977, J. Plasma Phys. 18, 257.

Bratenahl, A. and Yeates, C.M.: 1970, Phys. Fluids 13, 2696.

Carlqvist, P.: 1968, Solar Phys. 7, 377.

Carlqvist, P.: 1979, Solar Phys. 63, 353.

Carlqvist, P. and Alfvén, H.: 1980, Astrophys. Space Sci. 71, 203.

Cheng, C.-C.: 1977, Astrophys. J. 213, 558.

Chiu, Y.T. and Hilton, H.A.: 1977, Astrophys. J. 212, 873.

Craig, I.J.D. and McClymont, A.N.: 1981, Nature 294, 333.

Deinzer, W. and Stix, M.: 1971, Astron. Astrophys. 12, 111.

Foukal, P.: 1975, Solar Phys. 43, 327.

Foukal, P.: 1976, Astrophys. J. 223, 1046.

Furth, H.P., Killeen, J. and Rosenbluth, M.N.: 1963, Phys. Fluids 6, 459.

Galloway, D.J., Proctor, M.R.E. and Weiss, N.O.: 1977, Nature 266, 686.

Gilman, P.A.: 1970, Astrophys. J. 162, 1019.

Green, R.M.: 1965, in R. Lüst (ed.), Stellar and Solar Magnetic Fields, IAU Symp. 22, 398.

Heyvaerts, J., Priest, E.R. and Rust, D.M.: 1977, Astrophys. J. 216, 123.

Heyvaerts, J. and Kuperus, M.: 1978, Astron. Astrophys. 64, 219.

Heyvaerts, J., Lasry, J.M., Schatzman, M., Witomsky, G.: 1979, Preprint, Univ. of Paris Nord.

Hood, A.W. and Priest, E.R.: 1979a, Solar Phys. 64, 303.

Hood, A.W. and Priest, E.R.: 1979b, Astron. Astrophys. 87, 126.

Huba, J.D., Gladd, N.T. and Papadopoulos, K.: 1977, Geophys. Res. Lett. 4, 125.

Ionson, J.A.: 1982, Astrophys. J. 254, 318.

Jensen, E.: 1955, Ann.d'Ap. 18, 127.

Jockers, K.: 1976, Solar Phys. 50, 405.

Jockers, K.: 1978, Solar Phys. 56, 37.

Kuperus, M. and Tandberg-Hanssen, E.: 1967, Solar Phys. 2, 39.

Kuperus, M. and Raadu, M.A.: 1974, Astron. Astrophys. 31, 189.

La Bonte, B.J., Howard, R., Gilman, P.A.: 1981, Astrophys. J. 250, 796.

Leighton, R.B.: 1969, Astrophys. J. 156, 1.

Low, B.C.: 1977, Astrophys. J. 212, 234.

Low, B.C.: 1981, Astrophys. J. 251, 352.

Low, B.C., Munro, R.H. and Fisher, R.R.: 1982, Astrophys. J. 254, 335.

Meyer, F., Schmidt, H.U., Simon, G.W. and Weiss, N.O.: 1979, Astron. Astrophys. 76, 35.

Mouschovias, T.Ch. and Poland, A.I.: 1978, Astrophys. J. 220, 296.

Nakagawa, Y., Raadu, M.A., Billings, D.E. and McNamara, D.: 1971, Solar Phys. 19, 72.

Nakagawa, Y., Raadu, M.A. and Harvey, J.W.: 1973, Solar Phys. 30, 421.

Nakagawa, Y., Steinolfson, R.S. and Wu, S.T.: 1976, Solar Phys. 47, 193.

Newcomb, W.A.: 1960, Ann. Phys. 10, 232.

Papadopoulos, K.: 1979, in S.-I. Akasofu (ed.), Dynamics of the Magnetosphere, D. Reidel Publ. Co., Dordrecht-Holland.

Parker, E.N.: 1955a, Astrophys. J. 121, 491.

Parker, E.N.: 1955b, Astrophys. J. 122, 293.

Parker, E.N.: 1977, Astrophys. J. 215, 370.

Parker, E.N.: 1979, Cosmical Magnetic Fields, Oxford: Clarendon.

Parker, E.N.: 1981a, Astrophys. J. 244, 631.

Parker, E.N.: 1981b, Astrophys. J. 244, 644.

Pneuman, G.W. and Raadu, M.A.: 1972, Astrophys. J. 172, 739.

Priest, E.R. and Raadu, M.A.: 1975, Solar Phys. 43, 177.

Raadu, M.A.: 1972a, Solar Phys. 22, 425.

Raadu, M.A.: 1972b, Solar Phys. 22, 443.

Raadu, M.A.: 1978, in E. Jensen, P., Maltby and F.Q. Orral (eds.), Physics of Solar Prominences, IAU Colloq. 44, 167.

Raadu, M.A. and Kuperus, M.: 1973, Solar Phys. 28, 77.

Raadu, M.A. and Carlqvist, P.: 1981, Astrophys. Space Sci. 74, 189.

Raymond, J.C. and Foukal, P.: 1982, Astrophys. J. 253, 323.

Roberts, P.H. and Stix, M.: 1972, Astron. Astrophys. 18, 453.

Sakurai, T.: 1981, Solar Phys. 69, 343.

Schatten, K.H.: 1971, Cosmic Electrodynamics 2, 232.

Schüssler, M.: 1977, Astron. Astrophys. 56, 439.

Schüssler, M.: 1979a, Astron. Astrophys. 71, 79.

Schüssler, M.: 1979b, Astron. Astrophys. 72, 348.

Seehafer, N. and Staude, J.: 1979, Astron. Nachr. 300, 151.

Sheeley, N.R., Bohlin, J.D., Brueckner, G.E., Purcell, J.D., Scherrer, V. and Tousey, R.: 1974, Solar Phys. 40, 103.

Somov, B.V. and Syrovatskii, S.I.: 1980, in M. Dyer and E. Tandberg-Hanssen (eds.), Solar and Interplanetary Dynamics, 487.

Spicer, D.S.: 1982, Space Sci. Rev., to be published.

Spruit, H.C.: 1981, Astron. Astrophys. 98, 155.

Steenbeck, M., Krause, F. and Rädler, K.-H.: 1966, Z. Naturforsch. 21a, 396.

Steenbeck, M. and Krause, F.: 1966, Z. Naturforsch. 21a, 1285.

Stenflo, J.O.: 1976, in V. Bumba and J. Kleczek (eds.) Basic Mechanisms of Solar Activity, IAU Symp. 71.

Stenzel, R.L., Gekelman, W. and Wild, N.: 1980, in H. Kikuchi (ed.) Relation Between Laboratory and Space Plasmas, D. Reidel Publ. Co., Dordrecht, Holland, 145.

Stenzel, R.L. and Gekelman, W.: 1981, J. Geophys. Res. 86, 649.

Stix, M.: 1972, Astron. Astrophys. 20, 9.

Stix, M.: 1976, Astron. Astrophys. 47, 243.

Syrovatskii, S.I.: 1970, in E.R. Dyer (ed.), "Solar Terrestrial Phys." p. 119.

Syrovatskii, S.I.: 1977, Astron. Zh. (Letters) 3, 133.

Syrovatskii, S.I.: 1978, Solar Phys. 58, 89.

Syrovatskii, S.I., Frank, A.G. and Khodzhaev, A.Z.: 1972, Sov. Phys. - JETP Letters 15, 94.

Torvén, S.: 1979, in P.J. Palmadesso and K. Papadopoulos (eds.), Wave Instabilities in Space Plasmas, D. Reidel Publ. Co., Dordrecht, Holland, 109.

Tur, T.J. and Priest, E.R.: 1978, Solar Phys. 58, 181.

Uchida, Y. and Sakurai, T.: 1977, Solar Phys. 51, 413.

Vaiana, G.S., Krieger, A.S., Timothy, A.F. and Zombeck, M.: 1976, Astrophys. Space Sci. 39, 75.

Vaiana, G.S.: 1976, Phil. Trans. R. Soc. Lond. A. 281, 365.

Van Hoven, G., Ma, S.S. and Einaudi, G.: 1981, Astron. Astrophys. 97, 232.

Wild, N., Gekelman, W. and Stenzel, R.L.: 1981, Phys. Rev. Lett. 46, 339.

Figure Captions

Fig.1. The emergence and outward expansion of magnetic flux. Mass motions are indicated by heavy arrows. At the photosphere convective motions form magnetic field concentrations. From left to right: buoyant magnetic flux tubes rise towards the photosphere and expand out into the corona driving matter outwards. Current sheets form at surfaces of contact between different flux regions.

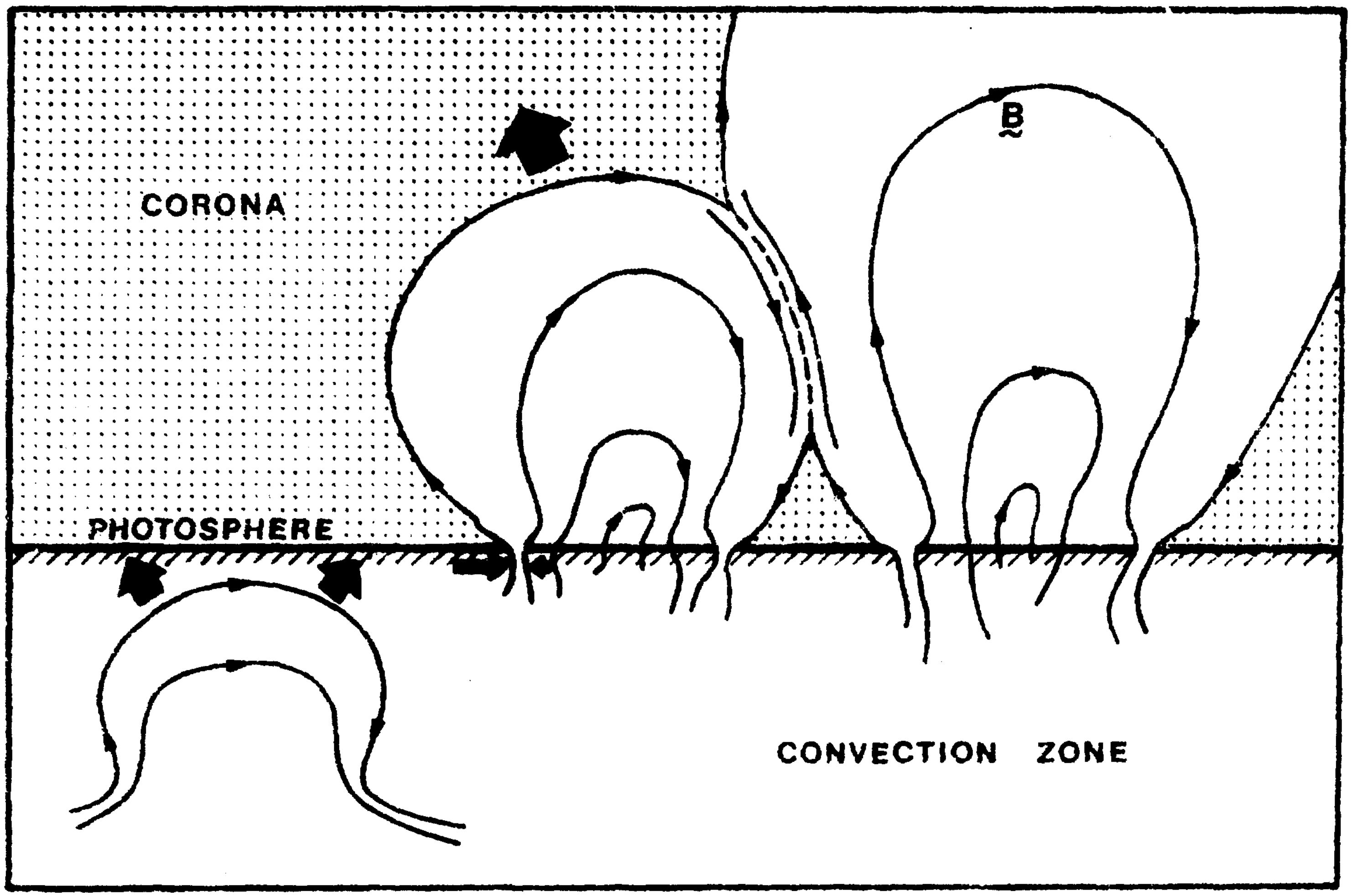

Fig. 1

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Key Words: Solar cycle, Magnetic Fields, Flux emergence, Solar corona, Current sheets, Coronal loops, Astrophysical plasmas