A TWO-LEVEL SOLAR DYNAMO BASED ON SOLAR ACTIVITY, CONVECTION, AND DIFFERENTIAL ROTATION

A. Bratenahl and P. J. Baum
IGPP, University of California, Riverside, CA 92521
W. M. Adams
The Aerospace Corporation, El Segundo, CA 92957

In orthodox dynamo theory (Stix, 1976), the two basic processes, generation of toroidal from poloidal field and conversion of toroidal into reversed poloidal field, are both located in the high β regime convection zone. Generation requires that regime, since its function demands it be driven by mechanical forces. But the function and therefore the operating requirements of conversion are entirely different, and there seems to be no à priori reason, other than historical tradition coupled with failure to recognize those differences, for the assumption that conversion must also operate there. Conversion transforms the topological structure of generated flux by altering the field line connectivity, so that the principal task performed is reconnection. Reconnection is a spontaneous process which must compress and accelerate plasma if any is present. Obviously it must perform much more work in the high β convection zone than in the low β solar atmosphere. It seems natural, therefore, to expect the reconnection aspect of conversion to be located there, where the least work needs to be performed. To transfer the generated flux there, we may add to conversion another spontaneous process: eruption of bipolar structure (Parker, 1955). To transfer the reconnected flux back down, we add to generation another mechanically driven process called topological pumping (Drobyshevski and Yuferev, 1974). Topological pumping depends on the diamagnetic effect of eddy-motion (Wiess, 1966), the kind possessed by supergranulation: 3-dimensional arrangement of isolated rising plumes, surrounded by a continuous network of descending sheet-like flow. In the two-level dynamo presented here, conversion may be observed directly, since we expect it to express itself in terms of all forms of solar activity: sunspots, flares, faculae, filaments, coronal structures including coronal holes, etc., and their organization and evolution in a "solar meteorology". It is clearly important to investigate a model that thus unites the two disciplines of solar activity and dynamo theory. Each strengthens the other and brings a greater unity to solar physics.

Although not all flux tubes above the photosphere get there by eruption from below (reconnection produces some), we assume that subduction from above accounts for all the flux tubes below. An important relation is thereby established between erupted flux, and previously subducted

M. Dryer and E. Tandberg-Hanssen (eds.), Solar and Interplanetary Dynamics, 29-32.

flux. We expect the subduction process to produce flux fibers containing a characteristic quantity of flux and a characteristic initial mass-per-unit length. Horizontal field, lying in the 600 km temperature minimum, ionization fraction $n_i/n_H = 10^{-4}$ (Giovanelli, 1977), loses its buoyancy by soaking up a sufficient mass of gas. During the 20 hr life of a supergranule, the characteristic quantity of flux will have soaked up the characteristically sufficient mass-per-unit length. This mixture of field and gas becomes frozen-in quickly and permanently as it is pulled below and becomes fully ionized. The effect of this is that the convection zone is maintained as a two-phase mixture of magnetized fibers confined to downflows in a sea of unmagnetized plasma.

The stretching action of differential rotation will eventually produce such a large increase in the fiber's field-to-mass-density ratio that the convective downflow can no longer prevent eruption (Parker, 1955). Zwaan (1978) suggests that the ubiquitous occurrence of facular points ($\gtrsim$1500 gauss, $\sim 10^{17}$ maxwells) is indicative of their preexistence as flux fibers before eruption and not some process operating at the time they appear. (In the model presented here, preexistence begins at subduction.) Zwaan further suggests that large numbers of fibers become packed into bundles and that sunspots result from their eruption. He avoided the term "flux rope", implying systematic twisting, since there is no obvious mechanism to produce it and observations do not support it.

Conversion must somehow reorient flux bundles from a westward-equatorward (eastward-poleward) tilt to a westward-poleward (eastward-equatorward) tilt <u>in both hemispheres at once</u>. This topological change in bundle-connectivity is not possible without invoking reconnection on a massive scale. We propose that it is best carried out in the solar atmosphere through an extended series of small elementary steps (Figure 1). Portions of neighboring bundles are erupted, reconnected; and then, while one of the new interconnections is subducted, the other expands out into the corona. The subducted interconnected link contributes to the required rotation in a stepwise reorgnization of the whole set of bundles. But since this series of steps is governed somewhat by chance, the process is untidy. For instance, the general field and its reversal is much less obvious than Hale's polarity law.

Consider two neighboring bipolar systems, Nos. 1 and 2, representing erupted portions of two independent bundles. Let No. 2 lie equatorward of No. 1. Reconnection leads to the sharing of flux of the two preceding (p) and following (f) polarities so as to create four flux cells with interconnections as follows: p_1f_1, p_2f_2, p_1f_2, p_2f_1 (Sweet, 1958; Bratenahl and Baum, 1976; Baum and Bratenahl, 1980). Cells with like indices we call <u>parents</u>, those with unlike indices, <u>daughters</u>. Conservation of flux in the transfer to the daughters requires that each of them receive the same amount, and the two parents must contribute equally. The daughter interconnecting the shorter p-to-f distance must lie underneath her sister, exposing weak horizontal field to subductive activity. As the topological pumping proceeds, more and more flux is transferred to both she and her sister, but when no more is available under the conservation

https://doi.org/10.1017/S0074180900067309 Published online by Cambridge University Press

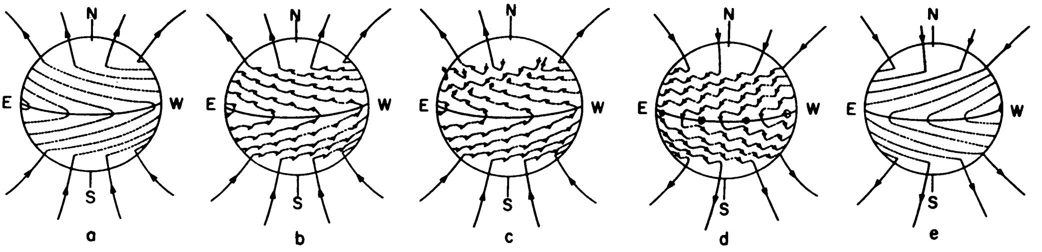

Fig. 1. Schematic representation of the rotation (from Adams, 1977).

rules, she disappears below, while her sister rises into the corona as an expanding loop system. The subducted daughter now forms a new link between the affected bundles and with an orientation in the convection zone corresponding to that which she had in the atmosphere. If that orientation corresponds to a rotation in the appropriate direction, the cycle is advanced; if not, it is retarded. The appropriate rotation can only be accomplished by the daughter named p_1f_2, which means that No. 2 must be somewhat westward of No. 1, its poleward neighbor. It may be demonstrated that the combination of differential rotation and the proper motion of polarity regions within bipolar structures, on the average, gives the necessary statistical advantage to steps that advance the cycle. The cumulative effect of thousands of such elementary steps reverses both the poloidal and toroidal components and thus ensures an efficient dynamo with little need for turbulent dissipation to get rid of unwanted flux.

The coronal loops undergo further reconnection processes; the net effect of which is the cancellation of the original polar fields and the merging of loops across the equator (Babcock, 1961). In this way, consistency is maintained with the corresponding changes in the convection zone.

This two-level dynamo model, if it has merit, could soon find confirmation in observations since nearly every step is linked to some aspect of solar activity, although subduction may present difficulties.

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https://doi.org/10.1017/S0074180900067309 Published online by Cambridge University Press

DISCUSSION

Stix: Does this model predict a time scale for the field reversal?

Bratenahl: The model is just at the beginning stage. All the real work is still to be done. If it is on the right track it will set its time scale.

Moore: Is the north-south tilt observed in the orientation of most active-region bipolar magnetic systems an important property for the operation of your model?

Bratenahl: No, not at all; the tilt can be either way providing it is not too large. The process is advanced by the statistically preferred reconnection geometry: preceding spot polward to follower spot equatorward.

Newkirk: How does the model which you are advancing, with the two field amplification located just below the photosphere, overcome the problem produced by field ropes being bouyed to the surface in a time short compared to any reasonable amplification time?

Bratenahl: We suppose amplification takes place near the base of super granulation ($\gtrsim$ 20,000 Km depth). The flux fibers and flux bundles are always in downflows. Bouyancy does not lead to eruption until it is sufficient to overcome downward drag forces.