

## EFFECT OF TURBULENCE ON EMERGING MAGNETIC FLUX TUBES IN THE CONVECTION ZONE

Sydney D'Silva and Arnab Rai Choudhuri  
Dept. of Physics  
Indian Institute of Science  
Bangalore, India.

**Abstract:** Working under the hypothesis that magnetic flux in the sun is generated at the bottom of the convection zone, Choudhuri and Gilman (1987; *Astrophys. J.* 316, 788) found that a magnetic flux tube symmetric around the rotation axis, when released at the bottom of the convection zone, gets deflected by the Coriolis force and tends to move parallel to the rotation axis as it rises in the convection zone. As a result, all the flux emerges at rather high latitudes and the flux observed at the typical sunspot latitudes remains unexplained. Choudhuri (1989; *Solar Physics*, in press) finds that non-axisymmetric perturbations too cannot subdue the Coriolis force. In this paper, we no longer treat the convection zone to be passive as in the previous papers, but we consider the role of turbulence in the convection zone in inhibiting the Coriolis force. The interaction of the flux tubes with the turbulence is treated in a phenomenological way as follows: (1) Large scale turbulence on the scale of giant cells can physically drag the tubes outwards, thus pulling the flux towards lower latitudes by dominating over the Coriolis force. (2) Small scale turbulence of the size of the tubes can exchange angular momentum with the tube, thus suppressing the growth of the Coriolis force and making the tubes emerge at lower latitudes. Numerical simulations show that the giant cells can drag the tubes and make them emerge at lower latitudes only if the velocities within the giant cells are unrealistically large or if the radii of the flux tubes are as small as 10 km. However, small scale turbulence can successfully suppress the growth of the Coriolis force if the tubes have radii smaller than about 300 km which may not be unreasonable. Such flux tubes can then emerge at low latitudes where sunspots are seen.

**Results:** (a) The drag on the flux ring due to the updraught of the large scale turbulence (eg: giant cells) is modelled as the drag on a cylinder moving perpendicular to its axis.

The flux ring released at the bottom of the convection zone moves radially out only if the velocity in the updraught is above a critical value  $u_c$ , so that the outward drag dominates over the Coriolis force.

Fig. 1 shows that  $u_c$  increases with increasing flux tube cross-sectional radius  $\sigma_0$ .  $u_c$  is independent of  $B_0$  except at unreasonably large magnetic fields of a 100 kG. It is clear that for the typical giant cell velocities of a  $100 \text{ ms}^{-1}$ , flux tubes cannot be dragged out radially.

(b) The efficiency of the small scale turbulence in suppressing the growth of the Coriolis force is measured by the angular momentum exchange time  $\tau$ . Smaller the value of  $\tau$ , greater is the efficiency of the process.

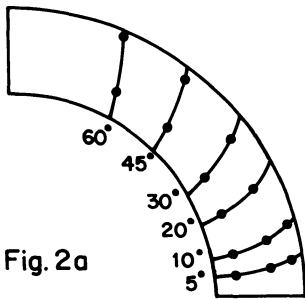
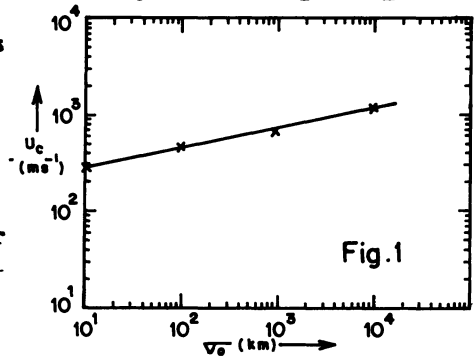


Fig. 2a

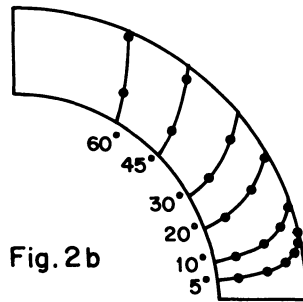


Fig. 2b

Fig 2a shows the trajectories of flux rings when released at the bottom of the convection zone at different latitudes. There is no transverse drag but  $\tau = 13$  hrs. The growth of the Coriolis force is successfully suppressed. Fig 2b shows how the mechanism fails when  $\tau$  is increased to 17 hrs.  $B_0 = 17$  kG in both cases. The critical  $\tau$  (i.e.  $\tau_c$ ), above which this mechanism fails, (1) increases with  $B_0$  (43 hrs for  $B_0 = 54$  kG) and (2) can be taken as  $\sigma_0^2$  divided by the turbulent viscosity. This dependence of  $\tau_c$  on  $\sigma_0$  puts an upper cutoff on the radii of the flux tubes that this mechanism can transfer out radially. It turns out that this mechanism fails for tubes of radii larger than a few hundred kms.

Conclusions: If the dynamo operates at the base of the convection zone and if we want the flux initially created at low latitudes to emerge at low latitudes, then

- (1) The flux tube sizes should be smaller than a few hundred kms ( $\sim 300$  km)
- (2) There should be small scale turbulence at the same scale ( $\sim 300$  km).