PHOTOSPHERIC SOURCES OF MAGNETIC FIELD ALIGNED CURRENTS

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Possible (small-scale) photospheric sources of coronal magnetic field aligned currents are discussed. Such currents are equivalent to local (small-scale) twists of the coronal magnetic field, and may cause field topologies that are (MHD or resistively) unstable, and thus contribute to the (small-scale) coronal activity.

One electro-motive force associated with photospheric magnetic fields is due to the asymmetry between ions and electrons as agents of conductivity and as agents of momentum transfer to the (dominant) neutral gas component. In the solar photosphere, where only some of the easily ionized heavier elements (Mg, Si, Fe, ...) are significantly ionized, the ratio of number density of electrons and ions to neutrals is very small, of the order of the total abundance of these elements, which is of the order 10^{-4}, by number. Due to the larger electron than ion mobility, electric currents are mainly carried by the electron component of the plasma whereas, because of the ions greater momentum transfer to the neutrals in collisions, the friction between the charged and the neutral components of the plasma is mainly due to the ions. Thus, the Lorenz force $\underline{i} \times \underline{B}$ acts mainly on the electron component of the plasma, whereas the balancing gas pressure gradient and gravity terms act mainly on the neutral component. A consideration of the momentum balance for each component of the plasma shows that the forces acting on the neutral component must be communicated to the electron component through friction to the ions and then, through an electric field to the electron component. Taken per unit volume, the forces on the three components of the plasma have similar magnitudes but, taken per particle, the forces on the charged components must be a factor n(neutral)/n(charged) larger than the forces on the neutrals. This leads to the presence of an (ambi-polar diffusion like) electric potential difference between the inside and the outside of magnetic flux concentrations (inside positive). The potential difference is of the order of the volt-equivalent of the temperature, times the number

P. B. Byrne and M. Rodonò (eds.), Activity in Red-Dwarf Stars, 601–603.

https://doi.org/10.1017/S0252921100096706 Published online by Cambridge University Press

ratio of neutrals to ions; i.e., of the order of 10 keV.

Because of the vertical stratification of the photospheric plasma and because the degree of ionization varies strongly with height (temperature), the emf across the interface varies strongly with height. At chromospheric levels and in the subphotosphere, the emf is much reduced due to hydrogen ionization, and a current-free equilibrium is not possible. In the limit where the current system is sufficiently efficient to effectively short out the photospheric emf, the momentum balance between the three plasma components can only be maintained by an additional $\underline{v} \times \underline{B}$ electric field, that is; the plasma has to rotate perpendicular to B and the interface. The significance of this effect depends strongly on the thickness of the boundary layer between field-free plasma and magnetic plasma: a smaller thickness implies a larger electric field and therefore a higher velocity, and a smaller thickness also implies that the plasma has to move a smaller distance for the topology of the magnetic field to become significantly distorted in the boundary layer. The boundary layer thickness is a result of the energy equilibrium in the boundary layer and is mostly controlled by radiative effects. Spruit (1976) has estimated the thickness to be of the order 10 km. This implies a typical plasma velocity of some 10 ms^{-1} for magnetic fields of the order 10^{-1} T. A significant distortion of the boundary layer magnetic field topology then takes some 10^3 seconds.

Another source of field-aligned currents is the small-scale vorticity associated with the horizontal velocity components of the granular velocity field. Numerical 3-D simulations of the interaction of granulation with a magnetic field on a small scale (Nordlund 1982), have shown that the magnetic flux concentrations in the photosphere continually readjust to fill out downdrafts created by the granular convection in the field free areas.

In summary, distortions of the photospheric magnetic field topology in the photosphere cause twists (field aligned currents) to propagate along field lines up into the coronal magnetic field. For small scale magnetic loops, these currents have a duration which is long compared to the propagation time of Alfven waves along the loop. This results in quasi-static twists of the coronal field lines, rather than propagating Alfven waves. The magnetic field aligned currents associated with such twisted fields may cause resistive MHD instabilities similar to Tokamak instabilities (Waddell et al 1979, Carreras et al 1980), and my thus be of importance for the small scale chromospheric and coronal activity.

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https://doi.org/10.1017/S0252921100096706 Published online by Cambridge University Press