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Alpha-Effect, Current and Kinetic Helicities for Magnetically Driven Turbulence, and Solar Dynamo

Gaetano Belvedere[1]*, V. V. Pipin[2,3] & G. Rüdiger[1,3]
[1]*Institute of Astronomy, University of Catania, Viale A. Doria 6, 95125 Catania, Italy.*
[2]*Institute for Solar-Terrestrial Physics, P.O. Box 4026, 664033 Irkutsk, Russia.*
[3]*Astrophysikalisches Institut Potsdam, An der Sternwarte 16, D-I4482 Potsdam, Germany.*
**e-mail: gbelvedere @alpha4. ct. astro, it*

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Extended abstract

Recent numerical simulations lead to the result that turbulence is much more magnetically driven than believed. In particular the role of *magnetic buoyancy* appears quite important for the generation of α-effect and angular momentum transport (Brandenburg & Schmitt 1998). We present results obtained for a turbulence field driven by a (given) Lorentz force in a non-stratified but rotating convection zone. The main result confirms the numerical findings of Brandenburg & Schmitt that in the northern hemisphere the α-effect and the kinetic helicity $\mathcal{H}_{\rm kin} = \langle \mathbf{u}' \cdot \mathrm{rot}\, \mathbf{u}' \rangle$ are positive (and negative in the northern hemisphere), this being just opposite to what occurs for the current helicity $\mathcal{H}_{\rm curr} = \langle \mathbf{j}' \cdot \mathbf{B}' \rangle$, which is negative in the northern hemisphere (and positive in the southern hemisphere). There has been an increasing number of papers presenting observations of current helicity at the solar surface, all showing that it is *negative* in the northern hemisphere and positive in the southern hemisphere (see Rüdiger *et al.* 2000, also for a review).

Mass conservation requires that $\partial \rho' / \partial t + \bar{\rho}\, \mathrm{div}\, \mathbf{u}' = 0$.Notice, that density has been assumed as homogeneous and density fluctuations vary in time. We do *not* adopt the inelastic approximation. For the turbulent energy equation we simply adopt a polytropic relation. In the sense of the 'τ-approximation', the spectrum of the given magnetic fluctuations field has been approximated by $\mathcal{B} \propto \delta(k - \ell_{\rm corr}^{-1})\, \delta(\omega)$ with $\tau_{\rm corr} \simeq \ell_{\rm corr}^2 / \nu$. The turbulence may develop under the influence of a large-scale magnetic field $\bar{\mathbf{B}}$ and the gravity g. For the current helicity we find

$$\mathcal{H}_{\rm curr} = \frac{2}{5} \frac{\tau_{\rm corr}^3}{\ell_{\rm corr}^2} \frac{\bar{B}^2}{\mu_0} \frac{\langle {B^{(0)}}^2 \rangle}{\mu_0 \rho c_{\rm ac}^2} (\mathbf{g} \cdot \mathbf{\Omega}). \tag{1}$$

The current helicity is thus *negative* in. the northern hemisphere.

The next step is the α-effect. Only the most important component, $\alpha_{\phi\phi}$, will be discussed. We obtain

$$\alpha_{\phi\phi} = -\frac{1}{5} \frac{\tau_{\rm corr}^2}{c_{\rm ac}^2} \frac{\langle {B^{(0)}}^2 \rangle}{\mu_0 \rho} (\mathbf{g} \cdot \mathbf{\Omega}). \tag{2}$$

The α-effect proves thus to be *positive* in the northern hemisphere and negative in the southern hemisphere. Current helicity and α-effect have opposite signs, their ratio being

$$\frac{\alpha_{\phi\phi}\bar{B}^2}{\mathcal{H}_{\rm curr}} = -\frac{\mu_0}{2}\frac{\ell^2_{\rm corr}}{\tau_{\rm corr}}. \tag{3}$$

The observed negative sign of the current helicity is reproduced, as well as the positive sign of the α-effect (in the northern hemisphere).

Our model yields for the kinetic helicity

$$\mathcal{H}_{\rm kin} = -\frac{8}{15}\frac{\tau^3_{\rm corr}}{\ell^2_{\rm corr}}\frac{\bar{B}^2}{\mu_0\rho}\frac{\langle B^{(0)^2}\rangle}{\mu_0\rho c^2_{\rm ac}}(\mathbf{g}\cdot\mathbf{\Omega}), \tag{4}$$

which is *positive* in the northern hemisphere and *negative* in the southern hemisphere. If a rising eddy can expand in a density-reduced surrounding, then a *negative* value of the kinetic helicity is expected. The magnetic-buoyancy model, however, leads to another result. There is *no* minus sign between α-effect and kinetic helicity, but nevertheless the minus sign is present in the relation between α-effect and current helicity, and the α-effect is positive.

Thus, for the solar dynamo, there is no indication, at least in the bulk of the convection zone, for a negative α-effect, which, in current dynamo theory, is necessary to account for the butterfly diagram of solar activity in the light of helioseismology. Of course, this does not exclude the location of the dynamo action deeply in the convection zone, or in the boundary layer (Belvedere *et al.* 1991), where a negative α is expected. Otherwise, we should abandon traditional dynamo theory and investigate a possible dynamo action strongly modified by meridional circulation, that is usually neglected in conventional dynamo.

References

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