§14. Generation of Magnetic Field in Thermal Convection in a Rotating Spherical Shell

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In order to obtain a hint of possible scenario of generation and maintenance of geomagnetic field we make a direct numerical simulation of a system of MHD equations and a detailed analysis of the numerical data. The molten iron in the outer core of the Earth is modelled by an electrically conducting Boussinesq fluid contained in a spherical shell sandwiched by two concentric spheres which rotate around a common axis with a constant common angular velocity Ω. The inner boundry is hotter than the outer.

There are four dimensionless parameters which control this dynamical system, that is, the Prandtl number $P_r = \nu/\kappa$, the Rayleigh number $R_a = \alpha\gamma\Delta T d^4/\kappa\nu$, the Taylor number $T_a = (2|\Omega|d^2/\nu)^2$, the magnetic Prantl number $P_m = \lambda/\kappa$, and the radius ratio η of the two spherical boundaries. Here, ν is the kinematic viscosity of fluid, κ the thermal diffusivity, α the thermal expansion coefficient, γ a gravity constant, ΔT the temperature difference between the two boundaries, d the shell thickness, and λ the electrical resistivity.

The simulation is performed in two steps. First, a steady thermal convection velocity field without magnetic field is realized starting with a stationary thermal conduction state superimposed by random perturbations in the velocity field. The values of parameters chosen are $R_a = 3200$, $T_a = 8000$, $P_r = 1$, and $\eta = 0.5$, for which the initial thermal conduction state is slightly unstable to small perturbations. Five pairs of cyclonic and anti-cyclonic vortex columns, which arrange alternately, are realized in the steady state (see Fig.1). Then, a small random magnetic field is seeded in the steady state and the full MHD equations are solved numerically. For $P_m = 0.12$ a time-dependent weak magnetic field is generated which drifts eastward relative to the vortex columns and changes periodically in time.

The regions of strong magnetic field are confined in some restricted domains of peculiar shape In Fig.1 we show the spatial structure of the velocity and magnetic fields around the central axis of an anti-cyclonic vortex which is one of the regions of strong magnetic field. Here, the blue lines represent the magnetic flux lines, the red/white lines the streamlines. The magnetic field is generated on red regions. The flow spirals clockwise into the anti-cyclonic vortex while going away from the equatorial plane. The transparent and yellow iso-surfaces cover high-vorticity and high-magnetic fields regions, respectively.

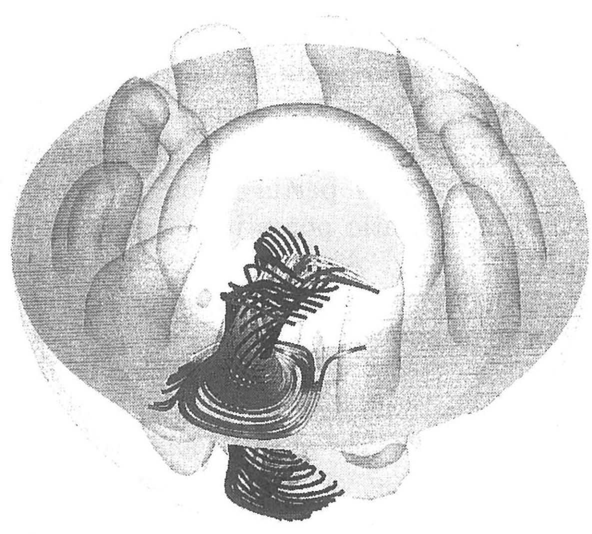

Fig.1. Intensification of magnetic field by concentrate-and-stretch mechanism.