# §19. Dipole and Octapole Field Reversals in a Rotating Spherical Shell

Ochi, M.M., Kageyama, A., Sato, T.

The magnetic field generation by a magnetohydrodynamic (MHD) dynamo finds many applications in planetary and astrophysical objects. It is well known that the Sun and the Earth have magnetic fields dominantly dipolar and that these fields may reverse polarity. The magnetic field is believed to be sustained by dynamo action in the convection regions. Fluid motions of the highly conducting medium of the convection regions in the presence of a magnetic field induce electric currents, which themselves generate the magnetic field. The essential three-dimensional, non-linear, and self-consistent nature of the dynamo problem makes computer simulation a very important tool and this is the objective of our research.

The physical system consists of an inner spherical core at a high temperature; an outer spherical surface that is kept at a low temperature; and an intermediate conducting compressible fluid. The system rotates at a constant angular velocity. The conducting fluid is studied by the MHD equations.

In a previous work, Kageyama and Sato [1] clearly explained the dipole field generation in a rotating spherical shell in terms of the so-called $\alpha\omega$ mechanism. The fluid generation mechanism was shown to be clearly related to the well organized structure of the fluid motion in convection columns aligned to the rotation axis.

In the present simulation we choose parameter settings, and initial and boundary conditions that would result in greater thermal convection compared to the previous simulation [1]. To achieve this, we increase the temperature difference between the inner and outer boundaries of the spherical shell. The Taylor and Rayleigh numbers are $5.88 \times 10^6$ and $3.36 \times 10^4$ respectively.

The integration of the MHD equations in spherical coordinates $(r, \theta, \phi)$ is based on the finite difference method. The grid numbers $(N_r, N_\theta, N_\phi)$ are chosen to be equal to (50,38,64) to achieve sufficient accuracy at reasonable CPU time. This simulation required about 300 hours of CPU time on the NEC/SX-4 supercomputer.

The boundary conditions are velocity equal to zero and magnetic field has only a radial component. This guarantees that the Poynting vector $\mathbf{E} \times \mathbf{B}$ has no radial component on the boundaries. This ensures that any magnetic field must be a consequence of the dynamo action in the bulk of the spherical shell.

The simulation starts from an unstable hydrostatic and thermal equilibrium state with no magnetic field. A temperature perturbation is introduced that causes the convection motion to begin. After a short time, the system reaches a saturation energy level. The convection motion pattern is verified to be well organized in five pairs of alternating cyclonic and anti-cyclonic convection columns whose axis are parallel to and encircle the rotation axis. Later on, a random and weak magnetic field perturbation is introduced. In the linear regime the magnetic field increases exponentially as the convection motion pattern remains constant. In the nonlinear regime, when the magnetic energy becomes large, time fluctuations are observed in the average kinetic and magnetic energies. The convection column pattern is distinct for different times. Re-organization of the convection columns occurs several times during the simulation. The breaks and recombinations of the columns and the changes of the drift motion velocity and direction make the convection motion structure and consequently the magnetic field structure very complicated. The average magnetic energy alternates between two fluctuating energy levels. The lower level is approximately equal to the kinetic energy and the upper level is about five times larger. Different nonlinear regimes thus occur. Three flip-flop energy transitions are observed in the simulation time. The simulation time is about 15.4 times the resistive diffusion time. In the first flip-flop energy transition the reversal of the dipole component of the magnetic field occurs. In the other two transitions the dipole component does not reverse polarity but on the other hand the octapole component reversals are observed. The dipole is observed to be the main symmetric component in the whole simulation. The octapole is the second most important symmetric contribution to the total magnetic field. The observation of flip-flop transitions between different magnetic energy levels and the magnetic dipole or octapole field reversals at each energy transition are new features in this kind of research [2]. We adopt a simple picture to study the MHD dynamo and successfully obtain the dipole field generation and its reversal. This suggests that the intermittent dipole reversal of the Earth's magnetic field is part of the intrinsic nature of a MHD open system. Specific physical conditions are not required to observe the dipole reversal in our research.

Reference

1) Kageyama,A. and Sato,T., Phys. Rev. E 55, 4617 (1997).

2) Ochi,M.M., Kageyama,A. and Sato,T., Phys. Plasmas 6, 777 (1999)