§15. Axial and Equatorial Magnetic Dipoles in a Rotating Spherical Shell

Ishihara, N. (Dept. of Physics, Nagoya Univ.), Kida, S.

The existence of a magnetic field in rotating spherical celestial bodies such as the Sun and its planets has long been attracting scientific interest by offering such questions as how it is generated and why the dipole component is often dominant. Thermal convection of an electrically conducting fluid in celestial bodies is one of the most probable dynamo mechanisms. There are three elements essential for the realization of this convection dynamo: rotation, spherical geometry, and convection (by nuclear reaction or phase transition).

As a simple model in which these elements are incorporated, the thermally driven dynamo in a rotating spherical shell has been extensively studied by numerical simulation.[1–4] In this model, a given temperature difference between the inner and outer spheres drives a convection of an electrically conducting fluid confined in a spherical shell rotating at constant angular velocity, which in turn intensifies the magnetic field. This is the dynamo action.

Different settings of simulations are devised depending on the purpose of dynamo research. We perform our simulations in two steps.[2] First, starting with a slightly unstable thermal conduction state superimposed by random disturbances, we perform a purely nonmagnetic simulation to obtain a fully developed thermal convection of either steady or unsteady state which is independent of initial small disturbances. Then, a random weak magnetic field is seeded and its temporal evolution is investigated by a full MHD (Magneto-hydrodynamic) simulation. In this way we may elucidate the magnetic field intensification mechanism by convection.[3] There are five control parameters in the present system, the Rayleigh number Ra, the Taylor number Ta, the Roberts number Ro, the Prandtl number Pr, and the ratio η of the radii of the outer and inner boundary spheres (see ref. 2 for definition). We are particularly interested in the phenomenon at large values of Ra and Ta as it is anticipated to be the case for the Sun and the Earth.

Simulation results are summarized as follows. Two types of magnetic dipole fields are generated by thermal convection composed of Taylor Proudman (TP) columns in a rotating spherical shell. One is equatorial dipole in which the magnetic dipole moment is perpendicular to the rotation axis is realized at a smaller Rayleigh number shown in Fig. 1. The other is the axial dipole in which the magnetic dipole moment is parallel to the rotation axis is realized at a larger Rayleigh number shown in Fig. 2. Their structure is robust and persists over the entire simulation period, which is two and eight magnetic diffusion times for Case I and Case II, respectively.

Table I. Parameters and flow characteristics.

$\eta = 0.5$, $Pr = 1.0$, $Ta = 1.6 \times 10^6$.

	Case I	Case II
Type of dipole field	equatorial	axial
Rayleigh number Ra	1.6×10^4	3.2×10^4
Number of TP columns	6	9
Roberts number Ro	0.02	0.1
Critical Roberts number	0.075	0.149
Magnetic diffusion time	50	10

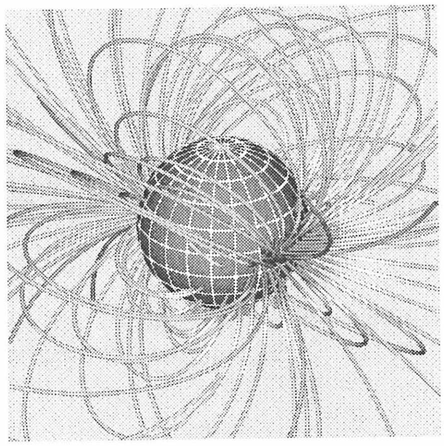

Fig. 1. Equatorial magnetic dipole for Case I

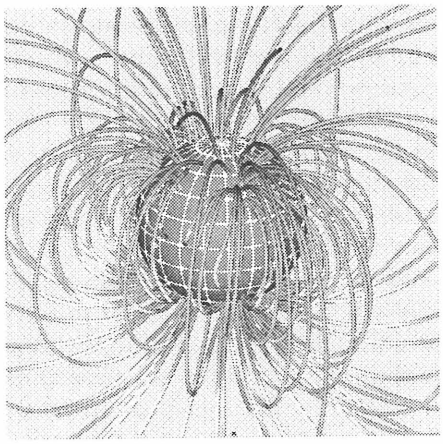

Fig. 2. Axial magnetic dipole for Case II

References

1) Kageyama, A. et al., Phys. Plasmas **2** (1995) 1421.

2) Kida, S., Araki, K. and Kitauchi, H., J. Phys. Soc. Jpn. **66** (1997) 2194.

3) Kitauchi, H. and Kida, S., Phys. Fluids **10** (1998) 457.

4) Ishihara, N. and Kida, S., J. Phys. Soc. Jpn. (in press)