§17. Dynamo Mechanism in a Rotating Spherical Shell: Competition between Magnetic Field and Convection Vortices

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It is well known that celestial bodies have their intrinsic magnetic fields. Most planets in the solar system have dipolar fields whose axes are nearly parallel to their rotation axes, e.g. for the Earth and Jupiter, or are much inclined, e.g. for Uranus and Neptune. It is widely believed that the origin of these magnetic fields should be attributed to the dynamo action by electrically conducting fluids in their interiors . In the case of the Earth, for example, the north-south symmetry of the magnetic field structure at the core-mantle boundary together with the Taylor-Proudman theorem, which states a tendency of two-dimensionalization of fluid motions in a rotating system, strongly suggests that the dynamo action due to convective motions of electrically conducting fluids in the outer core may be responsible for generation of the geomagnetic field. In order to understand the mechanism, we performed a direct numerical simulation of the magnetohydrodynamic equation of an electrically conducting Boussinesq fluid in a rotating sherical shell which is driven by a temperature difference between the outer and inner boundaries against a gravity force pointed to the system center.

Simulation results are summarized as follows[1,2]. A strong axial magnetic dipole field having the magnetic energy 15 times larger than the kinetic of thermal convection is realized. Cyclonic and anti-cyclonic convection vortices, which rotate, respectively, in the same and opposite directions of the system rotation, are generated and play a primary role in the magnetic field intensification. The magnetic field is intensified through the stretching of magnetic lines of force in three particular places of the convection fields, namely, inside anti-cyclones, between cyclones and their western neighboring anti-cyclones, and between anti-cyclones and the outer boundary. A 'twist-turn' loop of intense magnetic flux density accompanied with spiralling lines of force is identified as a fundamental structure which yields the dominant contributions both to the toroidal and poloidal components of the magnetic fields (Fig.1). Various types of competitive interaction between magnetic field and convection vortices are taking place throughout different stages of evolution. Among others, a creation-and-annihilation cycle of magnetic field and convection vortices in the statistically equilibrium state is particularly interesting, which is composed of three sequencially recurrent dynamical processes, that is, the generation of convection vortices by the Rayleigh-Bénard instability, the growth of anti-cyclones and the intensification of magnetic field by concentrate-and-stretch mechanism, and the break-down of vortices by the Lorentz force followed by diminution of magnetic field (Fig.2).

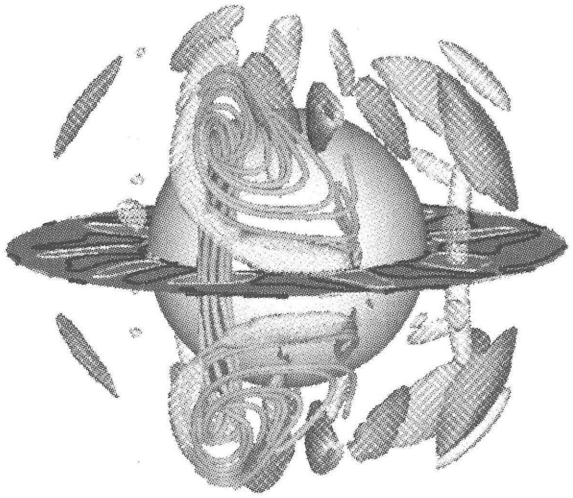

Fig. 1. Connection between a cigar-shaped strong magnetic blob in an anticyclone and a banana-shaped one outside

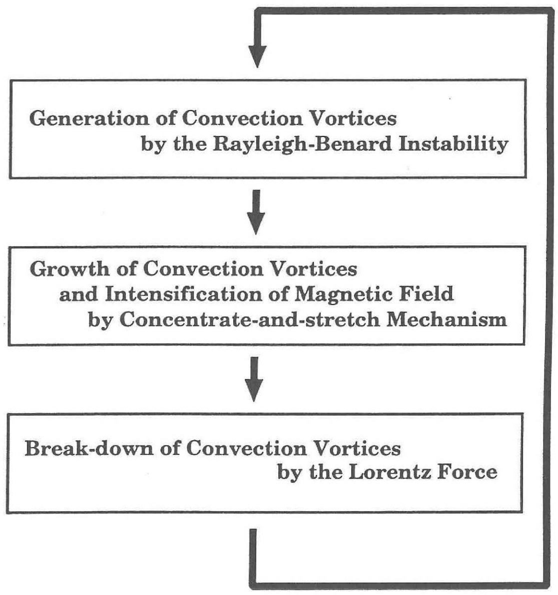

Fig. 2. Schematic illustration between magnetic field and convection vortices

References
1) Ishihara, N. and Kida, S., J. Phys. Soc. Jpn. **69** (2000) 1582.
2) Kida, S. and Ishihara, N., J. Plasma Fusion Res. **77** (2001) 355.