§ 26. Equatorial Magnetic Dipole Field Intensification in a Rotating Spherical Shell

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It is well known that many rotating celestial bodies, including the planets of the Solar system, have their own magnetic dipole fields. The axis of the dipole exhibits disperse behaviours. For some planets, such as the Earth, Jupiter and Saturn, the dipole axis is close in direction to the rotation axis, but for others, such as Uranus and Neptune, the two axes cross with large angles. Moreover, the dipole axis reverses its direction from time to time. The reversal is periodic for the Sun, but chaotic for the Earth. It is an unresolved interesting problem whether such diverse behaviours of the dipole fields arise from the difference in the physical properties of the bodies or in the physical parameters such as the rotation rate, the body size, and the strength of convection.

It is believed that such magnetic fields are originated from the interior of the celestial bodies themselves and that a convective motion of electrically conducting fluids in the bodies is one of the most probable dynamo mechanisms. This idea motivates a number of researchers to numerical simulation analysis of the thermally driven MHD dynamo in a rotating spherical shell. This simple dynamical system retains three essential elements, that is, convection, rotation, spherical geometry, for understanding the dynamo mechanism in a rotating spherical body. In fact, some of the characteristic features of the real magnetic fields, such as the dominance of dipole component and the reversal of dipole axis, the local activity and the westward drift of the magnetic field, are realized at least qualitatively. [1)]

Recently, the present authors have found two kinds of magnetic dipole fields. [2)] One is the equatorial dipole whose axis is on the equatorial plane of a rotating spherical shell, and the other is the axial dipole whose axis is on the rotation axis. The former is realized for relatively weak convection, whereas the latter is for stronger convection. How and where is the magnetic field intensified in each of these two cases ? We analyze the equatorial dipole field in this study and the axial dipole field in a companion article. [3)]

The simulation results are summarized as follows. [4)] A dynamo mechanism by thermal convection of an electrically conducting fluid in a rotating spherical shell is investigated by numerical simulation analysis of the MHD Boussinesq equations. The magnetic field is intensified, by stretching of magnetic field lines, along outgoing streamlines emanating from stagnation points in the convection velocity field so long as the magnetic field is weak. Once the magnetic field grows comparable in magnitude with the velocity field, however, the structure of the latter is deformed and the mechanism of magnetic field intensification is altered. The eastward drift of the convection vortices accelerated through the Lorentz torque creates a wavy zonal flow on which acceleration and deceleration are repeated periodically. The magnetic field is intensified, again through stretching of magnetic field lines, on the accelerating parts of the zonal flow predominantly near the equatorial plane. This establishes the magnetic dipole field with axis on the equatorial plane rotating around the rotation axis of the spherical shell (Fig. 1).

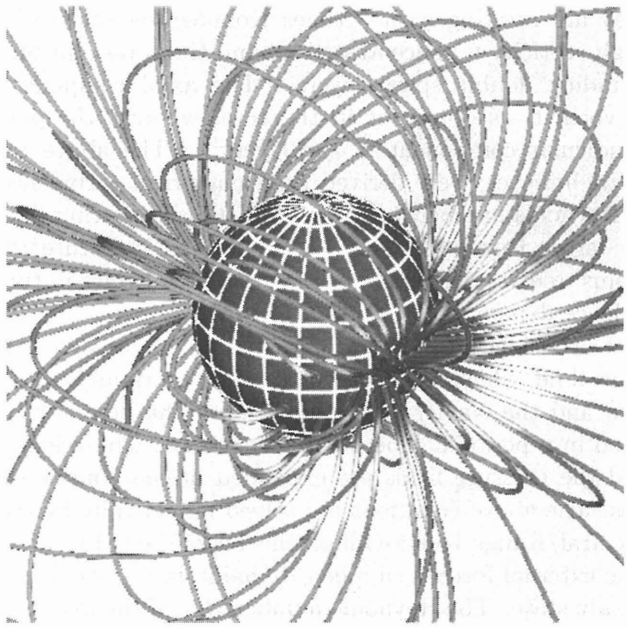

Fig. 1. Equatorial Magnetic Dipole Field. The magnetic field in vacuum outside of the outer sphere is represented with magnetic flux lines.

References

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