§15. Generation Mechanism of a Dipole Field by MHD Dynamo

Kageyama, Akira and Sato, Tetsuya

Computer simulation of a magnetohydrodynamic dynamo in a rotating spherical shell is performed. Strong magnetic field, whose energy is larger than the convection kinetic energy, is generated by the MHD dynamo process. Expansion of the generated magnetic field by the spherical harmonics Y_ℓ^m indicates that the dipole moment $(\ell, m) = (1, 0)$ is the strongest mode. Generation mechanism of the dipole field is examined in detail.

We consider the following system: An electrically conducting fluid is confined in a spherical shell region between two concentric spheres. The temperatures of both the inner and outer spherical boundaries are uniform and fixed; hot and cold. There is a central gravity in the direction of the center of the spheres. The whole system is rotating with a constant angular velocity. Thermal convection motion of the MHD fluid in this rotating spherical shell is self-consistently calculated by solving the MHD equations in the spherical coordinate system. Second order finite difference method is used for the spatial difference and the fourth order Runge-Kutta-Gill method is used for the time integration.

We have reported that thermal convection motion in a rotating spherical shell is organized as a set of columnar convection cells (convection columns)[1]. The convection columns are almost straight and parallel to the rotation axis when the rotation rate is sufficiently high. There are two kinds of convection columns; cyclonic and anticyclonic columns. They alternately encircle the inner spherical boundary. The flow in each convection column has a corkscrew trajectory. The helicity of the velocity is negative in the northern hemisphere and positive in the southern hemisphere.

A weak random magnetic field is seeded after the convection motion is saturated. The seed magnetic field exponentially grows by the MHD dynamo process.[2] The generated magnetic field is dominated by the dipole moment.[3] We investigated the generation mechanism of the dipole field by dividing the magnetic field into two parts; toroidal and poloidal field.

There are two strong toroidal flux, one in northern hemisphere and the other in the southern hemisphere. Their direction is antisymmetric about the equatorial plane. The poloidal field is generated when a toroidal field line is drawn toward the inner spherical boundary at a boundary region between a cyclonic column and an anticyclonic column. Helical flow in the convection columns stretches and twists the field line so that a poloidal component is generated. At this time, the term $-\mathbf{v}\cdot\mathbf{j}\times\mathbf{B}$ becomes positive which means a dynamo effect. This poloidal field generation process can be interpreted as an α-effect.

The toroidal field is converted from the poloidal field by the differential rotation. This is a so called ω-effect. The existence of the ω-effect is proved by a numerical experiment of a kinematic dynamo. We take the velocity field data from the above explained dynamic MHD convection simulation. Under this velocity field, we perform a kinematic dynamo simulation in which the time development of the magnetic field is calculated. In this case, a magnetic field is generated and its structure is the same as that of the dynamic simulation: The dipole moment is the strongest. We, then, put off the differential rotation component from the velocity field. We performed another kinematic dynamo simulation under this velocity field with no differential rotation and found that the magnetic field did not grow. Therefore, we can conclude that the differential rotation is necessary for the toroidal field generation. In summary, the dipole field generation observed in this simulation is explained by the well-known α-ω dynamo.

References

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