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The effect of boundary layers on dynamo action (III)

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We have been performing numerical simulations for an MHD dynamo model in a rotating spherical shell. In this study, we investigate the effect of boundary layers on dynamo action. We impose rigid boundary conditions and modify our code in order to resolve structures of the velocity and the magnetic fields within thin boundary layers. As a result of the above calculation, it turns out that the structure of the magnetic and the velocity fields for the rigid boundary condition is different from that for the stress-free boundary condition. We further find that the diffusion at the CMB is so large that we cannot rely on the so-called frozen flux approximation there.

We have been performing numerical simulations for an MHD dynamo model in a rotating spherical shell through numerical computations, in order to examine fundamental behavior of the velocity and the magnetic fields. In this thesis, we put much emphasize on an important role of the boundary condition of the velocity field; in particular the difference between the stress-free boundary condition and the rigid boundary condition. In the case of the rigid boundary condition, thin boundary layers appear at both the ICB (inner-core boundary) and the CMB (core-mantle boundary); they are known as the Ekman layers. Although there are many papers in which the behavior of the boundary layers was investigated, few papers have dealt with the structure of the magnetic field inside the boundary layers and their effect on the mechanism of MHD dynamo action.

In this thesis, we first examined the structures of the velocity and the magnetic fields for the stress-free boundary condition, using the computer code which was developed at the early stage of our series of studies. Next, we drastically modified the computer code, so as to be capable of dealing with the boundary layers by taking at least 10 grid points inside these layers and hence making precise computation there. With this modification,it became possible for us to make reliable simulation for the rigid boundary condition.

Then it turned out that we should be more careful for the rigid boundary condition than for the stress-free boundary condition. Variations of the structure in the r direction are so violent that we cannot resolve fine structures if grid points are coarse as was the case for our old computer code. In the case of the rigid boundary condition, a strong toroidal magnetic field is created inside the boundary layers by strong shear flow there. The behavior of the poloidal magnetic field is the same as for the stress-free boundary condition; we can see strong concentration of the magnetic field in the convection columns. At mid-latitudes, however, the structures are different between the stress-free and the rigid boundary conditions. In the case of the free boundary condition, the magnetic field is captured in the rearward columns at high-latitudes and move to the forward columns at low-latitudes; here, `rearward' and `forward' are referred to with respect to the drift direction of convection columns. In the case of the rigid boundary condition, however, the magnetic field is captured at the edges of the pair of eddies which are created near the CMB as a result of merging of convection columns. The magnetic field is wound by the eddies and a strong toroidal field appears at mid-latitudes. Through the results of a series of numerical simulations, we point out how important the boundary conditions are in examining the behavior of the magnetic field not only inside the boundary layers and in their vicinity but also in the deep interior of spherical shell.