Numerical experiments of MHD dynamo in a rotating spherical shell with a free-slip top boundary and a no-slip bottom boundary

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In recent years, according to the progress of computer resources, three-dimensional simulations of MHD dynamo in rotating spherical shells have been carried out vigorously in order to investigate generation and maintenance mechanisms of the sun and the planetary magnetic fields. Most of the simulations performed so far use both free-slip or both no-slip conditions at the top and bottom boundaries. However these conditions may not be suitable for the solar convection zone. Recent helio-seismological results show that there exists a strongly stably-stratified layer, *tachocline*, at the bottom of the solar convection zone. This is a transition layer between the solar convection zone and the radiative zone underneath (Gough et.al,1996). The observations also find that the radiative zone rotates rigidly and there is a strong shear at the tachocline. It seems that the no-slip boundary condition may be suitable for the bottom boundary of the solar convection zone. On the other hand, because there is no rigid boundary there, the free-slip condition is suitable for the top boundary of the solar convection zone.

Under those backgrounds, we have carried out numerical experiments of MHD dynamo in a rotating spherical shell with a free-slip top boundary and a no-slip bottom boundary. By applying such mechanical boundary conditions, we can expect a strong zonal flow in the upper layer of the convection zone and hence a dynamo solution influenced by the omega effect, whose structure is different from alpha^2 type dynamo solutions obtained by a number of previous researches.

Non-dimensional numbers for the numerical experiments are the modified

Rayleigh number Ra=100, the Ekman number Ek=10^{-3}, the Prandtl number Pr=1, and the ratio of inner and outer radii 0.35, and the magnetic Prandtl number, Pm, varied from 5 to 50. Time integration of non-magnetic thermal convection is carried out until a quasi-steady state is established, and then MHD dynamo calculation is carried out starting from the quasi-steady state with a small random or a dipole magnetic field.

In the non-magnetic thermal convection case, we obtain well-organized spiral vortex columns aligned with the rotation axis. These vortex columns drift eastward. A strong eastward zonal flow is produced at the top of the spherical shell in contrast to the simulations with the both no-slip boundaries. The eastward flow has a maximum at the top of the equator, and expands latitudinally to the contact latitudes between the tangent cylinder and the outer spherical shell. The high-latitude westward zonal flow is not prominent compared with the simulations with the both free-slip boundaries.

Calculated magnetic fields fall into decay for the cases of initially random magnetic field. For the cases with initially dipole magnetic field, non-decaying, periodically oscillating magnetic fields are obtained for Pm=20 and 50, although magnetic fields fall into decay at Pm=5 and 10.

In the case of oscillating dynamo solutions, the strong eastward zonal flow, which is prominent in the case of non-magnetic thermal convection, does not appear, but a slow westward zonal flow is produced at the top of spherical shell. The omega effect expected for the strong zonal flows does not seem to operate effectively. Magnetic fields are concentrated in the negative vortex columns or negative vorticity areas at the bottom boundary layer. The vortex columns drift eastward, but the areas of strong magnetic fields drift westward. Magnetic energy is maximum when the magnetic fields concentrate in the boundary layer, whereas when they concentrate in the vortex columns, magnetic energy is minimum.