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The effects of the initial magnetic field on MHD dynamo in a rotating spherical shell

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In recent years, three-dimensional numerical simulations of MHD dynamo in rotating spherical shells have been carried out vigorously in order to investigate generation and maintenance mechanisms of magnetic fields in celestial bodies. In most of the parameter studies, the strong magnetic field or the result of magnet-convection calculation with strong magnetic field were adopted as a initial value of dynamo calculation. As a result, they obtained strong-field dynamo solutions. However, as pointed out in some studies, it may depend on the initial value of a magnetic field whether a self-sustained dynamo action is established.

In the present study, numerical experiments of a MHD dynamo in a rotating spherical shell are conducted in order to investigate the effects of the initial magnetic fields. We assume the boundaries to be co-rotating. The bottom mechanical boundary condition is always no-slip, whereas the top mechanical boundary condition is free-slip (FR case) or no-slip (RR case). The temperature at each boundary is fixed and isothermal. The outside of the spherical shell and the inner core are electrical insulators. In all the calculations, the Ekman number, the Prandtl number, and the ratio of the inner and outer radii are fixed to 10^{-3}, 1, 0.35, respectively. The magnetic Prandtl number is varied from 1 to 20, and the modified Rayleigh number is increased from 1.5 to 10 times the critical value. For each combination of the parameters, time integration of non-magnetic thermal convection is carried out until a quasi-steady state is established. After quasi-steady state was established, MHD dynamo calculation is performed with three different types of magnetic field as follows:

(a) the energy of the imposed magnetic field is two order of magnitude larger than kinetic energy of the quasi-steady state of non-magnetic thermal convection.

(b) the energy of the imposed magnetic field is equal to the kinetic energy of the quasi-steady state of non-magnetic thermal convection.

(c) the energy of the imposed magnetic field is two order of magnitude smaller than kinetic energy of the quasi-steady state of non-magnetic thermal convection.

The results as follows:

1) As the the energy of initially imposed magnetic field becomes small, larger magnetic Prandtl number is necessary for the establishment of self-sustained dynamo regardless of the dynamical boundary condition.

2) In the RR case, all the obtained dynamo solutions are the alpha-squared dynamo solutions.

3) In the FR case, the alpha-squared dynamo solutions are established when the initial magnetic energy is (a) larger than or (b) equal to the kinetic energy of the initial non-magnetic convection, whereas a two-layer weak dynamo solution is obtained when the initial magnetic energy is (c) smaller than the kinetic energy of the initial non-magnetic convection. In the cases (a) and (b), it is necessary for the establishment of self-sustained dynamo to increase the magnetic Prandtl number compared with the RR case.

Keywords: Convection in a rotating spherical shells, MHD dynamo, Initial magnetic field