A modern interpretation of magnetic instability

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Linear analysis was a basic and tractable methodology in the early stage of planetary dynamo researches. One of such linear problems was a kinematic dynamo in which time development of a small-amplitude magnetic field perturbation was analyzed in the presence of an arbitrary steady fluid motion. This helped us to understand what type of flow structure was effective in magnetic field amplification, what type of magnetic field structure naturally grew, and of course to confirm an MHD dynamo was possible. Another linear study was magnetic instability in which time development of small-amplitude magnetic and velocity perturbations were analyzed in the presence of an arbitrary static toroidal magnetic field. In general, a toroidal field confined in a rotating fluid sphere becomes unstable if the field intensity is strong enough. Early theoretical studies revealed the conditions for ideal instability without electric resistance (e.g. Acheson 1972). However, it is found that addition of a finite but not high resistivity enhances instability (e.g. Fearn 1984). The controlling parameter of the resistive instability is the Elsasser number. The critical Elsasser number is generally about O(10), implying that this gives an upper bound for planetary magnetic field intensity because a higher magnetic field intensity rather destroys the dynamo due to magnetic instability (Zhang and Jones 1994).

These linear studies seem to be inactive in the recent 25 years during which nonlinear self-consistent dynamo simulations become easy. However, we cannot neglect those classical studies because they elucidate fundamental physical processes underlying a complex planetary dynamo. Here I present an idea that magnetic instability plays an important, positive role in the dynamo process. First, the number of convective rolls (the azimuthal wavenumber) in the core is determined by the critical wavenumber of magnetic instability, which is the optimal wavenumber at which the magnetic field and velocity perturbations grow fastest and effectively transport internal heat to the mantle. Second, the growth rate of magnetic instability controls the magnetic field saturation in the core. Magnetic instability is, in some sense, an energy transport process from the axisymmetric to non-axisymmetric parts. Therefore, the energy flow to smaller scales is balanced by the opposite energy flow creating the axisymmetric magnetic field due to dynamo action. There is a possibility that equating two linear growth rates of magnetic instability and a kinematic dynamo gives a relation between the Elsasser number and the magnetic Reynolds number that is the control parameter of a kinematic dynamo problem. I will give a detailed explanation based on my recent numerical results of magnetic instability of axisymmetric toroidal field confined in a rotating inviscid fluid sphere.