液体金属の熱対流における水平磁場の強度とパターンとの関係

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Convection patterns of liquid metal under various intensities of horizontal magnetic field

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The natures of turbulence and large-scale flow pattern in the outer core are controlled by the magnetic field. It is important to know the basic behavior of flow in relation to the magnetic field, for understanding the flow patterns observed in real Earth and core dynamo simulations. We performed laboratory experiments of Rayleigh-Benard convection by using a liquid metal, in the range of Rayleigh number (Ra) from critical value to 100 times above it, under various intensities of a uniform horizontal magnetic field B. The range of Chandrasekhar number (Q), which is proportional to the square of the intensity of B, is from 0 to 1000. The vessel we used has a square geometry with aspect ratio five. Flow patterns were visualized by ultrasonic velocity profiling method, and time variations of convective flow structure were clearly observed. We recognized five flow regimes depending on Ra and Q, that is, (1) isotropic large-scale cell pattern, (2) anisotropic cell with larger flow velocity perpendicular to B, (3) short-period oscillatory behavior of rolls aligned in the direction of B, (4) rolls with random reversals of the flow direction, and (5) steady 2-D rolls. In the regime (4), a roll-like structure is dominant for most of the duration, while an emergence of new circulation near the wall triggers the global reorganization of the pattern causing reversal of the flow direction. The reversals of the flow occur randomly with the typical time interval between reversals much longer than the circulation time.

We also performed numerical simulations of thermal convection to compare with the results obtained by these laboratory experiments. We can easily extend the range of Q in numerical simulations, which is difficult in laboratory experiments due to the limitation of equipments. These numerical simulations are performed for three dimensional square box, with no-slip boundary conditions at all boundaries, fixed temperature at the top and bottom, and insulating at side walls. Both the Prandlt number and magnetic Prandtl number of the working fluid are set small to simulate liquid metals. Our numerical result successfully reproduced all regimes of convection patterns that observed in the experiments.

A regime diagram of convection patterns under a horizontal magnetic field is established in relation to Ra and Q. These flow regimes can be classified by Ra/Q, that is the ratio of buoyancy force to the Lorentz force. If buoyancy force is much larger than Lorentz force, the flow is turbulent and isotropic structure is dominant. Short-period of oscillation is observed where the ratio Ra/Q is lower than 100. Random reversals are observed at Ra/Q between 10 and 30, and convection pattern keeps steady roll at Ra/Q smaller than 10. This relation is valid for wide parameter ranges.