Characteristics of turbulent thermal convection in liquid metal under uniform magnetic field

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The convective flow in the outer core of the Earth is supposed to be extremely turbulent, because molten iron has very low viscosity and the spatial scale is large. It is important for the outer core dynamics that the flow behaves turbulently under the influence of rotation and magnetic field. In many numerical dynamo simulations, the values of Prandtl number and magnetic-Prandtl number are set around one, but these values for liquid metals are very low actually. Laboratory experiment with liquid metal is a useful way for studying such low Prandtl number system and highly turbulent flow, though the size is too small to realize self-sustained dynamo action. We focus on the microscopic processes that should be important in the outer core flow. Here we show the results of laboratory experiment on turbulent thermal convection, and compare them with numerical simulations under similar physical conditions.

The Ultrasonic Velocity Profiler method is used to measure the fine-scale velocity field of the flow occurring in the liquid metals. We succeeded in the direct measurement of velocity profile for the Rayleigh-Benard convection in liquid gallium, with and without uniform magnetic field. The geometry of the tank is rectangular one, and the system is not rotating. Measuring the horizontal velocity at several sites in the tank, many fluctuations are observed, that reflect turbulent behaviors of the flow. When we see the long-term tendency, we can reconstruct two-dimensional roll-like pattern. This roll-like pattern is supposed to be a kind of mean-flow which is the organized structure in the turbulence, and the small fluctuations may show the behavior of small vortices. The roll-like pattern shows clearly regular periodic behavior. This means that the roll structure gets longer and shorter laterally and periodically. Its frequency increases with the Rayleigh number. When we apply horizontal magnetic field along the roll axis of this convecting system, the fluctuating components of the flow are reduced remarkably and the mean velocity of the roll-like flow pattern is increased. The reduction rate of the fluctuation depends on the intensity of the applying magnetic field, and we established the criterion. When we apply vertical magnetic field, the flow velocity and frequency of the periodic behavior reduces as the effective Rayleigh number of the system decreases with the magnetic field.

We obtain a series of three-dimensional numerical results of thermal convection for comparison to the laboratory experimental data. Our numerical result reproduces oscillatory convection patterns as observed in the experiments. We report the results of systematic study on the nature of turbulence by varying Prandtl number and magnetic-Prandtl number.