
Experimental investigations of turbulent liquid metal Rayleigh-Bénard convection in various geometries and aspect ratios

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Abstract

A key area of research at the Department of Magnetohydrodynamics at HZDR focuses on the experimental investigation of Rayleigh-Bénard convection in liquid metals at very low Prandtl numbers, $Pr \sim 10^{-2} - 10^{-3}$, which is of great interest for geo- and astrophysics. The thermally driven convective flow dynamics of liquid metals are very different from moderate-Pr fluids, such as water. Owing to the large discrepancies in the diffusion of heat and momentum, significant differences between velocity and temperature fields occur. The large-scale convection (LSC) in liquid metals exhibits a significantly more pronounced intermittent behavior and higher turbulence at comparable Rayleigh numbers, Ra . Here, the thermal boundary layer (BL) thickness exceeds that of the viscous BL, exposing it to direct interaction with the turbulent flow. It is well-known that the intermittent behavior of the viscous and thermal BL's increase significantly at small Pr. The viscous BL in a liquid metal becomes turbulent at smaller Ra than comparable convection in gases or water. Thus, a stronger influence of the LSC on the thermal BL thickness and, furthermore, on the local properties of the heat transport is likely. Here, we present investigations in cylindrical convection cells of aspect ratio 1 and 0.5 as well as in a

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rectangular cell with a square base area of 1 m² and an aspect ratio of 25. Our flow measurements demonstrate that the reduction of the aspect ratio in the cylindrical cells increases the volatility of the LSC, one can even describe this as a collapse of the coherent LSC. Here, the single-roll structure of the LSC alternates in short succession with double-roll and triple-roll structures in time periods smaller than the turn-over time. Temperature measurements within the thermal BL reveal strong fluctuations of the BL thickness and increasing deviation from the Prandtl–Blasius–Pohlhausen profile with increasing Ra. Furthermore, we will show measurements of the temperature and velocity fields in the shallow convection cell. These experiments focus on the search for so-called turbulent superstructures with their special characteristics in low-Pr fluids. Another area of research is the behaviour of convection and heat transfer under the influence of an external magnetic field. In a cylindrical container placed in a vertical magnetic field, we were able to demonstrate the existence of wall modes in our experiment at sufficiently high field strengths. The stability of convective rolls in a shallow fluid layer subjected to a horizontal magnetic field was studied in detail. This allowed the onset of the first instabilities to be observed and the mechanism governing the transition from two- to three-dimensional roll structures to be identified.