Scaling of the local convective heat flux in turbulent Rayleigh-Bénard convection

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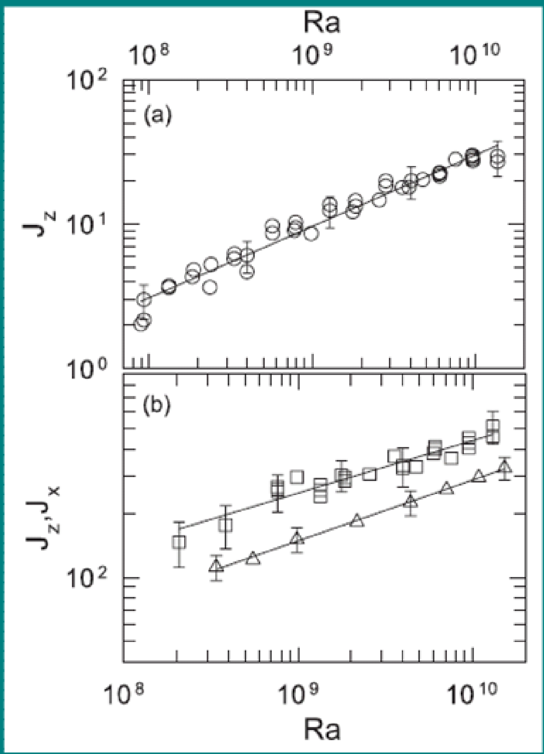
An important issue in the study of turbulent Rayleigh-Bénard convection is to understand how the total (normalized) heat flux, $\mathcal{J}(Ra,Pr) \equiv \langle J(\mathbf{r})\rangle_A$, averaged across the cross-sectional area *A* of a convection cell, which is also called the Nusselt number, changes with the two experimental control parameters: the Rayleigh number Ra and the Prandtl number Pr.



Early theories assumed that when Ra becomes very large, the bulk contribution of the viscous and thermal dissipations will be dominant over the boundary-layer contribution. Therefore, $\mathcal{J}(Ra,Pr)$ can be described by a simple power law, $\mathcal{J} \sim (RaPr)^{1/2}$, which is independent of viscous and thermal diffusivities of the fluid. In the experiment, the local velocity $v(\mathbf{r},t)$ and temperature $T(\mathbf{r},t)$ were measured simultaneously, from which we obtain the (normalized) local convective heat flux

$$J(\mathbf{r}) = \frac{\langle v(\mathbf{r},t)\delta T(\mathbf{r},T)\rangle_t H}{\kappa \Delta T}$$

where δT is the local temperature variation, ΔT is the temperature difference across the convection cell of height H, and $\langle \ldots \rangle_t$ represents an average over time *t*.

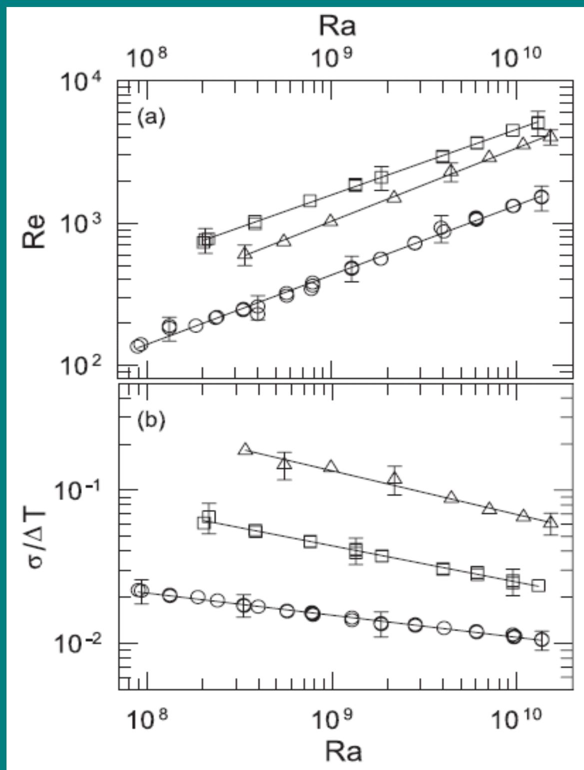


Figure 1(a) in the above shows that the vertical heat flux J_z at the cell center far away from the boundaries (circles) is well described by a power law $J_z \sim Ra^\beta$ with $\beta = 0.49 \pm 0.03$ (solid line), in good agreement with Kraichnan's prediction. On the other hand, the measured heat flux near the boundaries, as shown by the squares (near the sidewall) and triangles (near the conducting plate) in Fig. 1(b), reveal a different scaling behavior with $\beta \approx 0.24$. Figure 2 on the right shows the scaling behavior of the normalized velocity Re (a) and temperature variation $\sigma/\Delta T$ (b) as a function of Ra at the cell center (circles), near the sidewall (squares), and near the lower conducting plate (triangles). Again, the scaling exponents in the bulk region show different values from those near the boundaries. The local transport measurements thus allow us to disentangle boundary and bulk contributions to the total heat flux and directly check their respective scaling behavior against the theoretical predictions.