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Viscosity and Prandtl Number of Warm Dense Water as in Ice Giant Planets

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Abstract

The thermophysical properties in water-rich planets are important for understanding their radius, luminosity, and magnetic field. Here we calculate the shear viscosity η, isobaric heat capacity c_p, and Prandtl number

$$Pr = \eta \, c_p / \lambda$$

of warm dense fluid water using ab initio simulations and thermal conductivity (λ) values recently presented in [1, 2]. More specifically, the density (0.2–6 g/cm^3) - temperature (1000–50000 K) conditions considered in this work include states present in mini-Neptune to Neptune-sized planets. As a general result, we find that Pr ≥ 1 in the deep interior of Uranus and Neptune if they are adiabatic, whereas Pr < 1 if they are super-adiabatic. Our results lend some support to the suggestion of turbulent convection at Pr ≥ 1 to explain the peculiar magnetic fields of Uranus and Neptune [3].

Furthermore, we argue that double-diffusive convection in the Ice Giants Uranus and Neptune would require fine-tuning of the ratio of compositional gradient to superadiabaticity within a small factor of ~ 2,

$$1 < R_\rho^{-1} = \frac{\alpha_\mu}{\alpha_T} \frac{\nabla_\mu}{\nabla_T - \nabla_{\rm ad}} < 2.5 \quad .$$

Otherwise, and this is our conclusion, compositional gradients in Uranus and Neptune would be diffusive in nature and thus a significant amount of primordial heat could still be trapped inside. Further details can be found in [4].

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