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09/04/2024 – 11h00

LLB Salle 15

"New understanding of liquids and fundamental bounds in condensed matter physics"

Theories of gases and solids are well developed and date back 100-150 years ago. In contrast, understanding most basic thermodynamic properties (eg energy and heat capacity) of the third state of matter - the liquid state - turned out to be a long-standing problem in physics [1]. Landau&Lifshitz textbook states that no general formulas can be derived for liquid thermodynamic functions because the interactions are both strong and system-specific. Phrased aptly by Pitaevskii, liquids have no small parameter.

Recent theoretical results open a new way to understand liquid thermodynamics on the basis of collective excitations (phonons) as is done in the solid state theory. Differently from solids, the number of phonons is variable in liquids and decreases with temperature [1,2]. This effect is quantified in a phonon theory of liquid thermodynamics and explains the universal decrease of liquid constant-volume specific heat with temperature. One implication of this theory is that liquids can now be consistently understood on par with solids and are no longer “Cinderella of Physics” as believed until recently [1]. I will also explain how this picture extends above the critical point where the Frenkel line separates two physically distinct states on the supercritical phase diagram [3].

I will subsequently describe how this picture leads to the theory of minimal quantum viscosity in terms of fundamental physical constants including the Planck constant [4,5]. This answers the long-standing question discussed by Purcell and Weisskopf of why viscosity never drops below a certain value [6]. This also means that water and life and well attuned to the degree of quantumness of the physical world [6,7]. This, in turn, implies, that we can better understand fundamental physical constants from biological and life processes [7]. I will also show that bounds on thermal conductivity, thermal expansion, diffusion, elastic properties and speed of sound are similarly set by fundamental physical constants [5].

1. K Trachenko, Theory of liquids: from excitation to thermodynamics (Cambridge University Press, 2023); J Proctor, The Liquid and Supercritical Fluid States of Matter (CRC Press, 2021); K Trachenko and V Brazhkin, Reports on Progress in Physics 2016
2. M Baggioli, M Vasin, V Brazhkin and K Trachenko, Physics Reports 2020
3. C Cockrell, V Brazhkin and K Trachenko, Physics Reports 2021
4. K Trachenko and V Brazhkin, Minimal quantum viscosity from fundamental physical constants, Science Advances 2020
5. K Trachenko, Properties of condensed matter from fundamental physical constants, Advances in Physics (2023)
6. K Trachenko and V Brazhkin, Physics Today 74, 12, 66 (2021)
7. K Trachenko, Constraints on fundamental constants from bio-friendly viscosity and diffusion, Science Advances 2023