Thermodynamics trumps mechanics.

Goodbye Navier-Stokes?: Onsager's legacy to fluid mechanics.

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This talk, honoring Professor Dodge's legacy to Chemical Engineering at Yale, examines the ongoing conflict between thermodynamics and Newtonian mechanics (Boltzmann's dilemma). We begin by pointing out the surprising fact the truly fundamental equations governing continuum fluid mechanics and transport processes neither involve nor require the notion of velocity. Next, it is pointed out that Euler's (1755) assumption founding fluid mechanics some 250 years ago, namely that* $\mathbf{m} = \mathbf{n}_m$, is a constitutive assumption rather than an empirical fact of nature, contrary to what we learned as students. We discuss evidence for and against his relation. Since the validity of the Navier-Stokes-Fourier equations, and indeed the foundations of fluid mechanics, hinges on the correctness of Euler's implicit hypothesis, the issue is not moot. Irreversible thermodynamics, in the form of the Second law, plays a key role in framing the discussion. We refer here not to the usual side issue of demonstrating the positivity of the fluid's viscosity and thermal conductivity, but rather to the crucial role that Onsager's Reciprocal Theorem plays in resolving the question of whether Euler was right! Finally, some surprising applications of the theory are cited, such as the ability to predict, in nonisothermal liquids, both particle thermophoresis and thermal diffusion (the latter in thermodynamically-ideal mixtures).

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* $\mathbf{m} =$ momentum density (per unit volume), a dynamical quantity appearing in the Cauchy linear momentum equation embodying momentum conservation;

$\mathbf{n}_m =$ mass flux, a kinematical quantity appearing in the continuity equation embodying mass conservation.

Euler's equality, $\mathbf{m} = \mathbf{n}_m$, is equivalent to supposing that the fluid's "momentum velocity" $\mathbf{m}/\rho$ is equal to the fluid's "mass velocity" $\mathbf{n}_m/\rho$, enabling use of the single symbol $\mathbf{v}$ as an abbreviation for both, and thereby introducing the notion of "velocity" into fluid mechanics.

Howard Brenner, CV

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Born, raised, and educated in New York City, Howard Brenner received his Bachelor's degree in Chemical Engineering from Pratt Institute in 1950 and Ph.D. from New York University in 1957. His 50-year career as a chemical engineering faculty member includes New York University (1955-1966), Carnegie-Mellon University (1966-1977), the University of Rochester, the latter as Departmental Chair (1977-1981) and, since 1981, MIT, where he is currently W.H. Dow Professor Emeritus. Brenner has co-authored three fluid dynamics and transport phenomena books, namely *Low Reynolds Number Hydrodynamics* (1965) (still in print after 40 years), *Interfacial Transport Processes and Rheology* (1991), and *Macrotransport Processe* (1993). Honors include the American Institute of Chemical Engineer's respective "Lewis," "Walker," and "Alpha Chi Sigma" Awards, the American Society for Engineering Education's "Senior Research Gold Medal Award, " the American Chemical Society's Kendall Award in "Colloid and Interface Science," the "Bingham Medal" of the Society of Rheology, and, most recently, the American Physical Society's "Fluid Dynamics Prize." Brenner holds membership in the National Academy of Sciences, the National Academy of Engineering, the American Academy of Arts & Sciences, and is the recipient of an honorary doctorate from Clarkson University. Lifelong research interests focus on hydrodynamics and transport processes in fluid-particle systems, addressing both fundamentals and applications at the macroscopic and molecular levels. He has published about 250 papers in these fields. Most recently, his work — based largely on the novel view that volume can be transported though fluids without being accompanied by matter (even through solid walls, in much the same way as heat) — has questioned the traditional view of fluid-mechanical transport processes, especially in nonisothermal systems. This diffuse-volume transport notion has been used by him explain, quantitatively, such exotic transport phenomena as particle thermophoresis, thermal diffusion, and thermal transpiration in liquids and dense vapors. Previously, the mechanism underlying these transport processes was understood only for rarefied gases, and then only in gas-kinetic molecular terms, rather than in terms of Brenner's new hydrodynamic phenomenology.