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BOOK REVIEW

Essentials of Micro- and Nanofluidics: With Applications to the Biological and Chemical Sciences. By A. Terrence Conlisk. Cambridge University Press, 2013. 537 pages. ISBN 978-0-521-88168-5.

Nanotechnology took off at the turn of this century and is the direct descendant of the 1960s miniaturization of integrated circuits and the 1990s miniaturization of microelectromechanical systems (MEMS). Today's nanoelectromechanical systems (NEMS) are nanodevices, and the technology is grounded in the hard sciences of physics, chemistry, and biology. The word 'technology' here does not do fairness to the complex sciences required. Nanotechnology involves the manipulation of matter at the molecular scale, with at least one dimension of any resulting device sized from 1 to 100 nm. Governments and industries around the world are investing billions of dollars in the fledgling, interdisciplinary nanoscale science and engineering.

There are thousands of archival articles and dozens of books concerned with all aspects of nanotechnology. No one article or book can cover it all, and the present book is no exception. Terry Conlisk decided to focus on the fluidic aspects of nanotechnology. He covers thermodynamics, fluid mechanics, heat and mass transfer, colloids, electrostatics, electrokinetics, electrochemistry, and molecular and cell biology. Practical devices such as lab-on-a-chip, detectors for biological warfare agents, and artificial kidneys are briefly explored. Added to this impressive list is a bit on numerical simulations, the mathematical character of partial differential equations, molecular dynamics simulations, matched asymptotic expansions, and vector operations in curvilinear coordinates. All that is covered in a mere twelve chapters, four appendices, and 537 pages. An extensive bibliography and index are included. The present book is one of the very few in its subject that offers end-of-chapter exercises, as well as an instructor's solution manual.

Essentials of Micro- and Nanofluidics is intended as a textbook for a one-semester course for upper-level undergraduate and beginning graduate students in both science and engineering. Although it is assumed that the students have already taken an undergraduate class in several aspects of the book, no one student is expected to have taken classes in all the topics covered. The interdisciplinary nature of the subject necessitates that, but at what price and what choices did the author have? I will use fluid mechanics as an example discipline in an attempt to answer both questions.

The present coverage is inadequate for a student who did not take an undergraduate class in fluid mechanics. It is too terse to educate and to some extent serves to confuse the uninitiated. The choices Terry Conlisk had were limited. In my view, there were three choices: (i) make fluid mechanics a prerequisite; (ii) ask the students to spend two weeks reading a fluid mechanics book; and (iii) provide inadequate coverage in order to maintain a reasonable book's size. This reminds me of a physics professor in a top-ranked university who taught some years ago a graduate class in astrophysics. In order to cover the necessary fluid mechanics background, the professor asked the students to read Landau and Lifshitz's *Fluid Mechanics*, and gave the pupils two weeks to do it. Experts in fluid mechanics know well the difficulty of having Landau and Lifshitz's advanced textbook as a starting point, let alone having two weeks to finish it.

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I provide below a few examples of the inadequate, confusing coverage in that particular discipline. If I had unlimited space for this review, I would provide examples for the other aspects of the book.

The lowest-order relations between a flux and a potential that the present book provides for mass, momentum, energy, and electric current are first given without qualifications, and the subsequent corrections serve only to confuse. For example, it is stated that for a Newtonian fluid, the stress is linearly proportional to the rate of strain. But it is known that this relation breaks down at the micro- and nanoscale, even for an ordinarily Newtonian fluid such as air or water, when the flow deviates too far from the state of thermodynamics equilibrium. Those exceptional situations come later in the book, but by then the damage has been done; the students are not warned of the pitfalls either systematically or sufficiently early. Discussion of the no-slip condition on p. 109 is contradictory. At some scale even the continuum assumption breaks down, and one has to revert to molecular-based models. Figure 2.9 only serves to confuse this point.

When a gas flows in a micro- or nanochannel, compressibility effects become important. This is not discussed in § 4.4.1. Terminology used in the book is not always consistent. For example, the Navier–Stokes equations describe compressible as well as incompressible flows in the quasi-equilibrium state, but differently named equations are used for non-Newtonian fluids. Both the history and use of the no-slip condition are not quite accurate. For example, Prandtl was not the first to impose the no-slip condition. His main contribution was to split a high-Reynolds-number flow into a thin viscous layer – where the no-slip condition is enforced at the wall – and an infinite inviscid region. As one last example, the Laplace equation describes, among other things, the flow of an inviscid fluid. It does not describe a creeping flow, as mentioned on p. 128. The biharmonic equation has that honour. The author knows that well (p. 169), but did not do adequate editing and rewriting to correct obvious mistakes.

The copyediting is not up to Cambridge University Press's usual high standards. Too many words and phrases are repeated in the same or adjacent sentences. Simple rephrasing would have remedied that. In a book on fluidics, it is surprising to see the word 'fluid' misspelled as 'fliuid' (p. 25). For clarity, a comma is needed when a phrase follows a mathematical expression (equation (3.152), for example). Units should have a space after the numerical value and should not be italicized (insert in p. 97, for example). The usage of 'which' and 'that' is occasionally incorrect. Line drawings and photographs are not of the highest quality, and the font type changes from one figure to another.

I do not wish to be too critical of the book. I found it quite useful for people who already know most of the monograph's subjects. The breadth and depth of the many topics covered are at once the strength and Achilles' heel of the book. Probably a great teacher such as Dr Conlisk could make it work for the students, but the rest of us would find it challenging to do so. Maybe a massive open online course (MOOC) offered by Terry is our and the book's salvation.

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