that there is no such thing as the scientific method. Unlike many critics who have argued that on methodological grounds string theory is not science, Smolin recognizes that to impugn it for that reason, he must refute those who would say, "There are no methodological principles beyond 'science is what scientists do.' The rest is politics, networking, funding, or propaganda."

I believe that arguments about methodological definitions of science are traps to avoid. To worry that physicists' acceptance of string theory might make science indistinguishable from Millerism is an example of such a trap. A liberal view of methods in the short-term and a focus in the long-term on stability of descriptions, coherence with other parts of science, and empirical adequacy might be better places, albeit problematic ones, to start characterizing what science is. Smolin and Woit appear to think that it is time to cut the short-term benefit of the doubt for string theory, but many other physicists might be willing to let a little more time pass before rendering judgment.

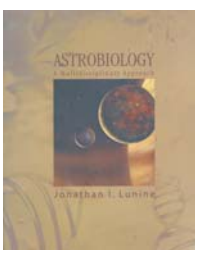
Astrobiology

A Multidisciplinary Approach

Jonathan I. Lunine

Pearson/Addison Wesley, San Francisco, 2005. $79.20 (586 pp.). ISBN 0-8053-8042-6

Astrobiology is the study of life's origins and potential distribution throughout the Milky Way galaxy. Conceptually, the discipline has been around for hundreds, if not thousands, of years; however, it is only since the analysis of the Martian meteorite ALH84001 and the discovery of extrasolar planets in the mid-1990s that astrobiology has received serious attention from the broad scientific community. Sustained by NASA funding, notably through the creation of the NASA Astrobiology Institute (NAI) in 1998, astrobiology entered the mainstream of scientific discourse—although some recalcitrants still can't resist referring to it as "bioastrology." The funding profile for astrobiology has changed sharply over the past year, but popular interest in the subject has not: Astrobiology courses are now well established in the curricula of many universities, which shouldn't be surprising because the subject is really about humankind and our place in the universe.



Astrobiology entered the fray as a disciplinary field only recently, thus the field is not overburdened with textbooks—good, bad, or mediocre. Most are introductory undergraduate textbooks in which the emphasis falls heavily on the "astro" and lightly on the "bio." *An Introduction to Astrobiology* (Open U. Press and Cambridge U. Press, 2004), edited by Iain Gilmour and Mark Sephton, is probably the leading example of that type of textbook. Jonathan Lunine's *Astrobiology: A Multidisciplinary Approach* is more balanced and much more ambitious in range and depth. The target audiences are graduate and upper-level undergraduate students, but the text is also an invaluable reference for researchers already working in the field.

Modern astrobiology demands familiarity with aspects of a wide range of disciplines, including astronomy, biology, chemistry, geology, physics, and planetary science. Lunine, a professor of planetary science and of physics at the University of Arizona in Tucson has been a key figure in the development of astrobiology as a discipline over the past decade. He is a researcher and, more important, a teacher. His textbook is the product of a well-tested lecture course and comes complete with questions that challenge and stretch students' imaginations rather than invite regurgitations.

The textbook, although undeniably multidisciplinary, has the feel of having been written from a physicist's perspective, albeit with more than a nod toward the biological sciences. After a brief historical overview, the following three chapters lay out the relevant basic physics (particles and forces), physical chemistry (quantum mechanics and bonds), and biochemistry (the cell and energy generation). The chapters are excellent introductions not only to the jargon but also to the science of the field, and they should be required reading for all aspiring astrobiologists who want to communicate successfully beyond their own specialist discipline. Of course, with only about 35 pages each, the chapters offer limited room for explanatory discussions; yet each concludes with a reference list and suggested supplementary reading material that can add depth.

The next 13 chapters provide a thorough discussion of the origins and diversity of life on Earth; the potential for life elsewhere in the solar system and among the nearer stars; the complications surrounding how we might detect and recognize that life if it's there; and a brief final coda on the development of self-awareness and intelligence. Again, each chapter is bolstered by suggestions for supplementary reading material. Lunine does an excellent job of weaving together the variegated threads, demonstrating how the interactions across disciplines are essential in establishing the tapestry of life.

Inevitably, with such a broad reach, the text contains some omissions. Perhaps the most notable one is a thorough consideration of the terrestrial geological record. It would also have been useful for Lunine to include some discussions of galactography—the study of locations and characteristics of Milky Way objects such as solar neighborhood stars, star-forming regions (for example, Orion and Scorpius–Centaurus), spiral arms, and the inner Milky Way. Instead, the author presents those environments as abstractions. Astrobiology discussions, particularly with non-astronomers, sometimes lack a sense of place and scale. What's where, and how did it get there? In the same vein, the discussion of extrasolar planets centers more on *how* to find them than on what we have learned from the planets we have found.

Yet in the final accounting, the above oversights are relatively minor, and one can imagine the screams from the publisher had the author tried to cram more material into a textbook already close to 600 pages long. *Astrobiology* is a welcome addition to the literature. It sets the bar at an exceedingly high level for future entries in the field.

Iain Neill Reid
Space Telescope Science Institute
Baltimore, Maryland

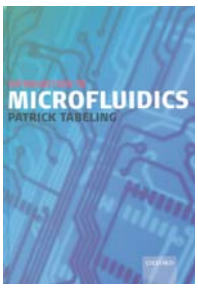
Introduction to Microfluidics

Patrick Tabeling (translated from French by Suelin Chen)

Oxford U. Press, New York, 2005. $99.50 (301 pp.). ISBN 0-19-856864-9

In preparing to review Patrick Tabeling's *Introduction to Microfluidics*, I was curious to learn the number of books on the subject that have appeared since 2000. A simple search on WorldCat, the Online Computer Library Center catalog, generated 11 other books published during this short period. These books collectively document the influences that first spurred interest in small fluidic devices, the hydrodynamic equations and boundary conditions pertinent to small-scale flows, recipe instructions for the design and fabrication of prototypes suitable for biomicroelectromechanical systems, and applications ranging from lab-on-a-chip devices to optofluidic components. Not included in the literature search were 10 or so lengthy review articles, about 20 conference volumes, and 2 journals devoted exclusively to microfluidics—*Lab on a Chip*, published by the Royal Society of Chemistry, and *Microfluidics and Nanofluidics*, produced by Springer. There is now even a $5000 prize, sponsored by *Lab on a Chip* and Corning Inc, awarded to "Pioneers in Miniaturization" under the age of 45.

The almost frantic output from academic and industrial researchers underscores the tremendous potential anticipated for technologies based on flow miniaturization. But gadflies like me remain a bit skeptical as to whether this field holds equal promise from a physics perspective, because most of the mechanisms for generating flow, mixing, or separation are reasonably well understood. Exceptions include subtleties involving multiphase flows, boundary conditions at liquid–solid interfaces, and the crossover from continuum to molecular-length descriptions of flow.



For the most part, an undergraduate course on the fundamentals of fluid, heat, and mass transfer is sufficient for understanding the operational basis of microfluidic devices. In addition, the prevalence of software packages geared toward flow optimization for complex geometries renders the design of even the most esoteric layouts accessible to those with a more limited background. I thus approached Tabeling's book with bias, hoping to find material suitably challenging for physics students despite the book being an introductory text.

The seven main chapters in *Introduction to Microfluidics* touch on the subjects of low-Reynolds-number flow and its consequences for miniature systems; transport processes critical to microfluidic devices, such as diffusion, dispersion, mixing, absorption, and separation; electrokinetic flows in the context of lab-on-a-chip systems; heat transfer and efficient thermal control with microscale heat exchangers; and deposition and sealing techniques for constructing microplumbing components. The book is based on graduate courses offered during 2001–03 at the Jussieu campus, the University of Paris VI: Pierre and Marie Curie, and the École Polytechnique. This target audience explains the author's informal presentation style, which pervades his ambitious attempt to cover all facets of microfluidics in one volume.

Tabeling anchors his whirlwind tour of the field with specific examples: He provides more than 170 drawings illustrating various concepts, geometries, and device realizations, and he includes occasional boxed inserts containing short mathematical derivations. Unfortunately, the presentation does not lend itself to conventional homework problems. Also, the references at the end of each chapter of the book, which was originally published in French in 2003, are not sufficiently comprehensive or up to date for those eager to tackle more advanced or specialized topics.

For example, physics students might enjoy learning more about the forces responsible for electrowetting, one of the more elegant methods for droplet actuation. Electrohydrodynamic forces, when coupled to the dynamics of a moving contact line, reveal some challenging problems; but the book's discussion of electrowetting, which is poorly described, is far too brief and is limited only to the Lippman equation. The two electrowetting references are geared more toward materials compatibility and device fabrication than fundamentals. The limited references miss substantial developments since 2002 that provide the hydrodynamic basis for the technique. Electrowetting devices represent just one category of a larger class of open microfluidic systems driven by surface acoustic waves, thermocapillary stresses, magnetic forces, and other electrocapillary phenomena—none of which are discussed at any length. Although droplet motion by surface-energy gradients is also considered, the explanation the author provides is not totally accurate. The fluid velocity depends on the gradient of the local curvature, as well as the square of the local droplet thickness, and not simply on the curvature as stated.

Unfortunately, Tabeling's desire for brevity leads in many cases to misleading descriptions, as, for example, with droplet evaporation. Many studies during the past decade have shown that evaporating droplets are not just subject to diffusion but also undergo complex processes as a result of boundary pinning, substrate wettability, thermocapillary and Marangoni effects, ambient saturation conditions, and vapor recoil effects, to name a few. Perhaps a second printing of this book will include more detailed descriptions and eliminate distracting misnomers and grammatical errors, due in part to the inexperience of the translator, a graduate student at MIT.

The same qualities then that make the book an entertaining and painless entrée into the field of microfluidics, however, may leave physics students dissatisfied, as several of the presentations are too sketchy, elementary, or misleading in their simplicity. When referring to molecular-dynamics studies of slip boundary conditions, for example, Tabeling incorrectly states that the critical shear rate above which substantial slip is possible at liquid–solid interfaces is of order 10^{13} s^{-1}, well beyond the realm of commonplace flows. The proper way to make contact between actual laboratory systems and molecular-dynamics simulations is through the relevant dimensionless quantities like the Reynolds, capillary, or Bond numbers. As known, a naive mapping of the length or time scales extracted from a Lennard–Jones interaction potential always leads to ridiculously high or low estimates in comparison to real experimental systems.

Despite these drawbacks, Tabeling's infectious excitement and broad interest in microfluidics and microhydrodynamic flows infuse the pages of this easy-to-read book. The illustrations and images are very useful in conveying concepts in a straightforward way. Readers who want a sweeping introduction to the various transport mechanisms and technologies at play will benefit from and enjoy this compact overview of the subject. *Introduction to Microfluidics* is likely to intrigue those interested in commercial devices who wish to peek under the covers to learn more about the fundamentals governing small-scale flows.

Sandra M. Troian
California Institute of Technology
Pasadena

Statistical Physics for Cosmic Structures

Andrea Gabrielli, Francesco Sylos Labini, Michael Joyce, and Luciano Pietronero
Springer, New York, 2005. $89.95 (424 pp.). ISBN 3-540-40745-6

The large-scale structure of the universe as revealed through galaxy and cluster