

Van der Waals Forces

A Handbook for Biologists, Chemists, Engineers, and Physicists

V. Adrian Parsegian

Cambridge U. Press, New York, 2006. \$110.00, \$50.00 paper (380 pp.). ISBN 0-521-83906-8, ISBN 0-521-54778-4 paper

Van der Waals forces—in competition with electrostatic interactions—are argu-

ably the most prevalent and relevant forces for understanding the properties of materials and living systems. Accordingly, research on these forces has enjoyed a long and rich history of funda-

mental physics contributions, and many expositions on their applications in chemistry, colloid science, and biology have been written. Adrian Parsegian's monograph *Van der Waals Forces: A Handbook for Biologists, Chemists, Engineers, and Physicists* is a highly original work that offers a welcome, stimulating, and useful addition to the literature.

The book succeeds in achieving two extremely ambitious goals. First, it sets out to demystify the classic theories from more than 60 years ago of Hendrik B. G. Casimir, Evgeny M. Lifshitz, and their coworkers in which dispersion interactions were first connected to the electromagnetic modes of continua. To that end, Parsegian discusses in detail the basic starting points and formal derivations underlying this statistical physics approach and its status relative to the earlier atomistic theories. Second, the book is intended as a how-to manual for biologists, chemists, engineers, and physicists. In this regard, a significant fraction of its 380 pages is devoted to a compilation and annotation of exact and approximate analytical results for dispersion interactions as explicit functions of the measured dielectric properties of real materials.

The book begins with the "Prelude," in which the long history and esthetic beauty of the subject are introduced. The reader learns about alternative approaches to dispersion interactions and begins to understand the respective strengths and limitations of those approaches and their reconciliations with one another. Chemists, biologists, and chemical engineers will be more famil-

iar with the classic long-range $1/r^6$ attraction between molecules in gases or colloidal particles in solution; physicists will be more familiar with the generic interactions between macroscopic objects arising from their perturbation of the electromagnetic spectrum of the intervening medium.

From the outset, the technical exposition is enriched by physical insights and clarifying, general remarks about the basic phenomena involved. For example, on page 20, in anticipation of the more systematic analyses that follow throughout the rest of the book, readers find the disarmingly simple statement, "A good rule of thumb is that interaction energies between two bodies in any geometry will be significant compared to kT as long as their separation is less than their size." Similarly, on the following page, readers are treated to a wonderful dimensional analysis of why a bug can't be too big if it wants to stick to the ceiling, and why it should have the right shape to do so.

The charming but substantive prelude is followed by "Level 1: Introduction." In this section, the essential ingredients of the modern theory of dispersion forces are presented, in particular the roles of imaginary frequencies in the electromagnetic spectrum, of zero-point energy, and of retardation effects. Of particular physical interest is the brief discussion of certain less familiar features of van der Waals forces, including repulsive interactions and torques between macroscopic bodies. An introduction to layered materials and the effects of spherical and cylindrical geometries is also presented.

The heart of the book, "Level 2: Practice," gives an account of how to calculate dispersion interactions from the general expressions of Lifshitz and others. The author gives tables of exact and approximate formulas for basic geometries and model systems—for example, for small and large separations, assuming no retardation; for small differences in permittivity; and so forth. At least as important as the tables are the accompanying essays on the tabulated formulas, which discuss the status of the various approximations involved, connections to the particle theory for gases and dilute suspensions (the Hamaker theory), the breakdown of pairwise additivity, generalizations to include ionic solution contributions, and the case of molecules and colloids interacting with substrates. This lengthy section ends with several extremely useful and edifying examples—including MathCad programs—of the actual computation of dispersion interac-

tions from both phenomenological models and measured spectra of the dielectric response for water and for particular hydrocarbons and metal systems of interest.

Just when readers are feeling good about having reached the end of the story, they are given an additional treat in the concluding section, "Level 3: Foundations." The author instructs readers in the mode summation approach of Nico van Kampen and colleagues by using it to derive general results of Lifshitz and coworkers and by working through the particular case of two semi-infinite media across a planar gap. He also shows how this fundamental theory can be generalized to multilayer systems, inhomogeneous media with spatially varying dielectric functions, and ion-containing anisotropic systems.

Throughout, the book contains several dozen problems of all kinds, with explicit solutions provided in an appendix, as well as a thoughtfully annotated bibliography of relevant primary and secondary sources. I can easily imagine *Van der Waals Forces* becoming an integral part of the personal libraries of the many types of scientists for whom it was written.

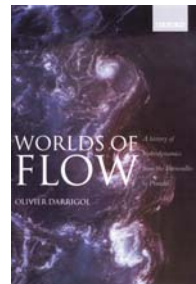
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Worlds of Flow

A History of Hydrodynamics from the Bernoullis to Prandtl

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Oxford U. Press, New York, 2005.
\$74.50 (356 pp.).
ISBN 0-19-856843-6



Olivier Darrigol is a distinguished historian of science who had previously published a prize-winning volume, *Electrodynamics from Ampère to Einstein* (Oxford U. Press, 2000), on another branch of

physics. His latest book, *Worlds of Flow: A History of Hydrodynamics from the Bernoullis to Prandtl*, will be of most interest to historians, especially those who already have some knowledge of the scientists, engineers, and scientific topics that the author covers.

The text is very mathematical. Darrigol repeats the detailed derivations of the earlier mathematicians, including their sidetracks and mistakes, but with modern vector notation and methods.

His book could also attract a wider audience: By skating over the details and gaining a broad view of the achievements and interactions of the pioneers, scientists who use hydrodynamics will find Darrigol's treatment interesting and entertaining. He covers more than a century of hydrodynamics in detail, from the 18th century to the early 20th century, when physicists began to tackle boundary effects in nonidealized flows.

In the 18th and 19th centuries there was a clear distinction between hydrodynamics and hydraulics, and the fields evolved independently. Hydrodynamics was the application of advanced mathematics to idealized flows rarely encountered by engineers, who used empirical formulas to make progress with practical hydraulics problems. Only in the 20th century were the challenges of real flows properly dealt with by physically based theories, and those developments, too, are well described by Darrigol. The early contributors to the tortuous development of the equations of motion of inviscid fluids include the Swiss mathematicians Leonhard Euler, Johann Bernoulli, and Johann's son Daniel; and the Frenchmen Joseph Louis de Lagrange and Jean le Rond d'Alembert. Although these names are now attached to their respective mathematical results, a great deal of overlap and interaction exists between each formulation.

One problem that the early theorists could solve was the motion of waves on a free surface. French mathematicians provided strong input, but most water-wave phenomena were well known in navigation contexts, both at sea and in canals, before they could be explained. British physicists paid more attention to such practical questions than did their continental peers; they provided useful solutions to those questions and added to fundamental theory. A striking example of the different approach by British hydraulic engineers was John Scott Russell's accidental discovery of what are now known as solitary waves. A canal boat, towed at high speed and then suddenly stopped, produced a large wave of permanent form that continued to progress independently along the canal. Russell's observations and the deductions from them were brilliant; his theoretical insights, however, were not very sound, and he was strongly criticized by his contemporaries—in particular in the work of George Biddell Airy, George Gabriel Stokes, and William Thomson (later known as Lord Kelvin).

Much more firmly based contribu-

tions to other aspects of wave theory were made by British mathematicians. Among them were Airy, who wrote an influential review, *Tides and Waves*, published in 1845, and Stokes, who studied finite oscillatory waves. Thomson made notable contributions to the theory of capillary waves, the understanding of three-dimensional ship-wave patterns, and the concept of group velocity.

The French civil engineer Claude Louis Navier was the first to break away from the concept of a perfect fluid by obtaining a hydrodynamic equation for viscous flow in 1821. Two other French mathematicians, Augustin Cauchy and Siméon Poisson, rediscovered Navier's equation before Stokes independently derived it in 1845, but it was many years before the Navier–Stokes equation became a standard tool in hydrodynamics. Stokes used the equation in the linear approximation to derive the formula for the velocity of a sphere sinking through a viscous fluid; but this method only helped for laminar flow.

In the 1860s, Hermann von Helmholtz invented another approach to the problem of fluid friction; his approach was based on vortex-like solutions of Euler's equations. He introduced the concept of a vortex sheet and first applied the theory to sound generation in organ pipes and then to vortex rings. His ideas were enthusiastically received and were followed up by his colleague and friend Thomson and other British mathematicians. The gap between small- and large-scale physics began to narrow. What is now called the Kelvin–Helmholtz instability was observed both in the laboratory and in the atmosphere, and a photograph of the experiment is presented and described in *Worlds of Flow*.

Stokes and Thomson studied other instabilities, but the two friends had different views about the roles of viscosity and surfaces of discontinuity. Lord Rayleigh studied inviscid flow between fixed walls and concluded that parallel flow without an inflexion point in the velocity profile is stable. The engineer Osborne Reynolds showed that for turbulence to occur in pipe flow, a small viscosity is essential. He demonstrated the concept experimentally and introduced the dimensionless ratio later named in his honor. Factors that impede ship motion, including the effects of large eddies, surface waves, and skin friction, were tackled by many mathematicians in the late 19th century. The decisive step to understanding skin friction was taken by the German mathematician Ludwig Prandtl, who

introduced the boundary-layer approach. Prandtl showed that viscosity is only significant in a thin layer near a solid surface and that flow outside the layer can be treated as inviscid. He went on to study the formation of turbulent boundary layers and the criteria for boundary-layer separation. Wing theory, the understanding of lift and drag, and the development of the whole of modern aeronautics have depended on his ideas.

Despite its extensive treatment of the history of hydrodynamics, I have a personal disappointment with *Worlds of Flow*: It is a pity that the author chose to

end the story with Prandtl, with only a passing reference to Geoffrey Taylor, a towering figure in British fluid mechanics whose life and contributions overlapped with Prandtl's. Nonetheless, by presenting in detail the interactions between many mathematicians and engineers, and by emphasizing the different styles characteristic of scientists in different countries, Darrigol has provided a fascinating insight into the development of hydrodynamics.

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Photonic Crystals Towards Nanoscale Photonic Devices

Jean-Michel Lourtioz, Henri Benisty, Vincent Berger, Jean-Michel Gérard, Daniel Maystre, and Alexis Tchebnokov
 (translated from French by Pierre-Noel Favennec)
 Springer, New York, 2005. \$99.00
 (426 pp.). ISBN 3-540-24431-X

Photonic crystals are artificial periodic structures in which electromagnetic wave dispersion can be engineered and controlled, in analogy to the way the bands of electrons in semiconductor crystals are manipulated. The field involves the discovery and creation of those types of photonic crystals that have interesting properties, and a photonic bandgap is only one such property. Today, a whole array of photonic crystals illustrate one aspect or another of basic science, fulfill various practical aims, or occasionally provide physically based pigments in living things.

The study of photonic crystals spans solid-state physics, physical optics, crystallography, quantum optics, electromagnetic engineering, and even biology. The range and escalation of the field have led to the defeat of most researchers' attempts to provide a contemporary follow-up to the beautiful introductory monograph *Photonic Crystals: Molding the Flow of Light* (Princeton U. Press, 1995) by John D. Joannopoulos, Robert D. Meade, and Joshua N. Winn. In the past 10 years a large number of books have emerged, but the very breadth of the subject means that such volumes as *Photonic Crystals: Advances in Design, Fabrication, and Characterization* (Wiley-VCH, 2004), edited by Kurt Busch and coworkers; *Photonic Crystals: Physics, Fabrication and Applications* (Springer, 2004), edited by Kuon Inoue and Kazuo Ohtaka; and *Electromagnetic Theory and Applications for Photonic Crystals* (CRC Press, 2005), edited by Kiyotoshi Yasumoto, have usually consisted of collections of discrete articles written by individual authors and supervised by editors. Many worthy writers have been defeated in their attempts to create a single comprehensive text.

In *Photonic Crystals: Towards Nanoscale Photonic Devices*, Jean-Michel Lourtioz and his colleagues have come out with an impressive major volume that covers many of the main themes of photonic crystals, but it required the concerted effort of six coauthors. The English version, thanks to translator