

Breaking down traffic congestion

Introduction to Modern Traffic Flow Theory and Control

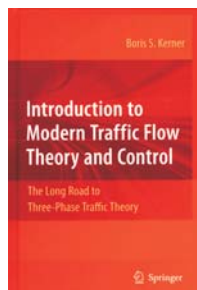
The Long Road to Three-Phase Traffic Theory

Boris S. Kerner

Springer, New York, 2009. \$129.00 (265 pp.). ISBN 978-3-642-02604-1

Reviewed by L. Craig Davis

In the past two decades, sensor-rigged highways in Germany and other countries have provided researchers with a considerable amount of data on rates of traffic flow (vehicles per hour), vehicle speed, and vehicle density (vehicles per kilometer). Those data are a boon for traffic researchers such as Boris Kerner



at German automaker Daimler AG. A former plasma and solid-state physicist, Kerner has virtually overturned the conventional theory of highway traffic flow and advanced the field to an extent not seen since the 1950s, when Robert

Herman, a physicist at General Motors, introduced statistical physics to traffic modeling.

Introduction to Modern Traffic Flow Theory and Control: The Long Road to Three-Phase Traffic Theory is Kerner's account of how he and his research group analyzed the highway data and developed their theory. They identified three distinct traffic phases: free flow, when vehicles move uninhibited; synchronous flow, when vehicles travel at speeds below those characteristic of free flow but still maintain high rates of flow; and the jammed phase, when vehicles come to a standstill in spots

and the flow rate drops to zero. The last two phases are called congested states. The researchers discovered that free flow does not spontaneously transform into the jammed phase but rather goes initially into the synchronous phase. Only from the second phase can jams nucleate. As far as I know, that finding had not been noted in previous research.

Although Kerner's three-phase theory has been controversial, he appears to have successfully refuted all major criticisms by showing that it works. One of the theory's novel features is the two-dimensional region of flow rate versus vehicle density that comprises the congested states. Previously, traffic engineers collapsed those data onto a single curve—the venerable fundamental diagram of traffic. Kerner and his colleagues have introduced three-phase models—which feature vehicle dynamics—that accurately reproduce observed traffic patterns. They have successfully applied the theory to identify congested phases in real-time traffic data and to predict travel times. And they have also developed a new algorithm for on-ramp flow control that reduces congestion and improves throughput.

The data collected from highways and subsequent theories developed from those data have made older books such as Adolf May's popular *Traffic Flow Fundamentals* (Prentice Hall, 1990) partially obsolete. *Introduction to Modern Traffic Flow Theory and Control* is a shorter and more readable description of traffic research than Kerner's previous book, *The Physics of Traffic: Empirical Freeway Pattern Features, Engineering Applications, and Theory* (Springer, 2004). Most of the mathematics is at the level of introductory calculus. Concepts are clearly illustrated with figures, and the book's useful glossary of traffic terminology should make the material accessible to graduate students in physics, mathematics, and engineering. Kerner describes and critiques the major traffic models going back more than 50 years and includes an extensive list of references. Much of his work has been published in *Physical Review E* and other refereed physics journals. In the

last chapter, Kerner briefly discusses his ideas on the future of theoretical traffic research.

I have a few minor criticisms. The author starts with empirical data and draws the conclusions that lead to his three-phase theory—a suitable way to begin. But he abandons that approach in chapter 3, in which he uses simulations to illustrate certain features of the theory before introducing the computational models that are required to do the simulations; that approach makes it seem as though empirical data were unavailable. Additionally, I found incorrect grammar usage that should have been spotted in the editorial process. Nonetheless, I highly recommend *Introduction to Modern Traffic Flow Theory and Control*. Three-phase theory must be taken seriously, and traditional analyses by traffic engineers should be revised. I hope the book will encourage the traffic research community to employ the concepts and methods that Kerner has so convincingly presented.

Philosophy of Mathematics and Natural Science

Hermann Weyl

Princeton U. Press, Princeton, NJ, 2009 [1949]. \$35.00 (311 pp.). ISBN 978-0-691-14120-6 paper

Mind and Nature

Selected Writings on Philosophy, Mathematics, and Physics

Hermann Weyl

(edited by Peter Pesic)

Princeton U. Press, Princeton, NJ, 2009. \$35.00 (261 pp.). ISBN 978-0-691-13545-8

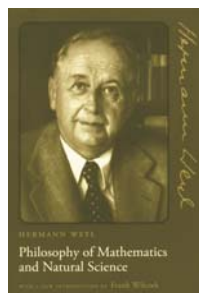
Any reader of PHYSICS TODAY probably knows Hermann Weyl (1885–1955) as an iconic mathematician who made fundamental contributions to diverse branches of mathematics—particularly analysis, number theory, and group theory. Readers also may well know about his work in mathematical physics: Together with Eugene Wigner, Weyl

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pioneered the application of group theory to quantum theory. He also initiated the gauge principle, in his unification of electromagnetism and gravity proposed in 1918 immediately after Albert Einstein's formulation of general relativity.

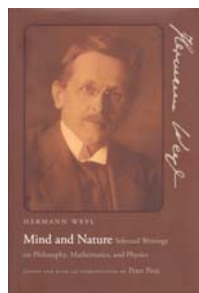
Weyl's genius had another aspect: his engagement with and writings on foundational, even philosophical, aspects of mathematics, physics, and the scientific worldview. His book *Philosophy of Mathematics and Natural Science* is a masterpiece. The original was written in German for the *Handbuch der Philosophie* and published in 1927. An authorized 1949 English translation by Olaf Helmer from Princeton University Press contained numerous corrections, additions, and six appendices spanning 80 pages. In view of the 20 years separating the German original and the American release, Weyl considered rewriting the book in English himself, but ultimately rejected the idea. In the preface, he writes, "How could I hope to recapture the faith and spirit of that epoch of my life when I first composed it ... after due literary preparations dashing off the manuscript in a few weeks?" The translation has long been out of print, so this recent republication, with a very fine introduction by Frank Wilczek, is to be highly valued.

Of course, every book, even one by a genius, is a creature of its time. So Weyl's discussions of some topics—especially in cosmology, molecular biology, and evolutionary theory, which have exploded since 1949—now seem either dated or too brief. But even in such cases, Weyl's grasp of the contemporary science is thorough and his awe at the intricacy and unity of nature and his open-mindedness about unsolved scientific problems make inspirational reading. Besides, when we consider foundational topics of mathematics or physics that were center stage in Weyl's time, his discussions are always both wise and thought-provoking. One example in the foundations of mathematics is Weyl's discussion of his doctoral adviser David Hilbert's formalism; to Hilbert's chagrin, Weyl was drawn to L. E. J. Brouwer's intuitionism. An example from physics is Weyl's discussion of quantum theory, which is full of expository detail from spectroscopy to noncommutativity and entanglement—Weyl admits that "the meaning of quantum physics ... is not yet clari-



fied as thoroughly as ... relativity theory" (p. 264). There are also wise yet very individual discussions of much more specific topics—for example, the nature of the continuum and why space is three-dimensional. Weyl's *Philosophy of Mathematics and Natural Science* should be on every mathematician's or physicist's bookshelf.

Weyl's *Mind and Nature: Selected Writings on Philosophy, Mathematics, and Physics* is of more interest to historians or to philosophers like me, but I still heartily recommend it to physicists and mathematicians. A selection of philosophical writings from the period 1921–55, it is beautifully edited with an introduction and scholarly endnotes by Peter Pesic. *Mind and Nature* includes several treasures: two lecture series, from 1932 and 1934; two letters from 1922—one by Weyl and the other by Einstein—about relativity theory's bearing on the idea of mechanism; and a touchingly personal essay from 1955 about "the part which philosophical reflection ... has played in my life" (p. 204). From that essay, it emerges—to the dismay of any philosopher trained in the analytic tradition!—that Weyl was profoundly influenced by Edmund Husserl's phenomenology and its roots in German idealism, a school of philosophy that tries to deduce



substantial conclusions about what we know and how we know it by analyzing experience.

There are other texts about Weyl's scientific legacy: His *Classical Groups* (1939), *Algebraic Theory of Numbers* (1940), and *Symmetry* (1952; all from Princeton University Press) and his *Theory of Groups and Quantum Mechanics* (Methuen, 1931; Dover, 1950) remain in print and are inspiring reads. Top-quality scientific and historical commemorations of his work and legacy continue to be published. Two examples are *Hermann Weyl's Raum-Zeit-Materie and a General Introduction to His Scientific Work*, edited by Erhard Scholz (Birkhauser, 2001), and *Groups and Analysis: The Legacy of Hermann Weyl*, edited by Katrin Tent (Cambridge University Press and London Mathematical Society, 2008).

Reading *Philosophy* and *Mind and Nature* was a poignant experience for me, since so many pages reminded me of how Nazism destroyed German science and philosophy. Taken together,

these books give a remarkably detailed and fascinating picture of Weyl's philosophical outlook in the last 30 years of his life. What a pleasure, what a privilege, to read and contemplate Hermann Weyl's monumental achievements.

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Ab Initio Molecular Dynamics

Basic Theory and Advanced Methods

Dominik Marx and Jürg Hutter
Cambridge U. Press, New York,
2009. \$80.00 (567 pp.).
ISBN 978-0-521-89863-8

The dynamics of molecules in a material or a chemical reaction can be simulated by calculating the time history of the internuclear coordinates according to the potential that governs internuclear motion. By the Born–Oppenheimer approximation, the potential is the electronic energy plus internuclear repulsion evaluated at a fixed internuclear configuration. Such simulations are useful in areas as diverse as nanoscale science, quantum photochemistry, combustion, biochemistry, catalysis, and atmospheric and environmental chemistry.

In the formative years of molecular dynamics simulations, the potential was represented by an analytic function, and only after hit-or-miss attempts to fit electronic-structure energy calculations or experimental data to potential functions could the dynamics be determined. However, about 35 years ago, a new approach began to replace that unsystematic, labor-intensive process. Direct dynamics, as it became known, does not require the fitting of the potential or force to an analytic function: The results of an electronic-structure calculation of the potential are used directly, without fitting, to advance the time step whenever the dynamics algorithm calls for energy or force. Direct dynamics began in the 1970s, and now a plethora of approaches are available in which either density functional theory or wavefunction theory is used to acquire the electronic energies. That this evolving field now has a pedagogical monograph in the form of Dominik Marx and Jürg Hutter's *Ab Initio Molecular Dynamics: Basic Theory and Advanced Methods* is a significant milestone.

The terms used in the book's title, and in the field in general, are often