

astrophysics has a real problem. What, then, is the experimental picture?

That is the question Clifford Will asks and answers in this readable and at times fascinating account of the modern history of experimental relativity. While theorists were sharpening their understanding of the theory, experimenters were busy too. Leading experimenters such as Robert Dicke, Leonard Schiff, Irwin Shapiro, and Robert Vessot—again, people who had established their names in other fields—turned the new tools of modern technology to the job of testing relativity and its foundations. They and their colleagues have tested some predictions of the theory to extraordinary precision, and they have come up with new kinds of tests that Einstein never dreamed of. The list of effects tested is long: gravitational redshift, deflection of light, perihelion shift, time delay, the Nordtvedt effect, the constancy of G , gravitational waves and the binary pulsar, dragging of inertial frames.

Learning the results of these experiments, however, is only part of the appeal of this book, and perhaps not the largest part. What impressed me most was its narrative style: Each experiment is a story, each experimenter a personality. Will gives us a sense of their motives, their feelings during crises, and their satisfaction when the experiment finally goes right. Take Einstein himself as an example. Will brings the man alive when he tells us that after explaining the "anomalous" perihelion precession of Mercury, Einstein "later wrote, 'for a few days, I was beside myself with joyous excitement,' and told a colleague that the discovery had given him palpitations of the heart." As another example, it is a bit of light relief to be told that the Stanford gyroscope experiment—one of the most difficult, time-consuming, and expensive that NASA has ever supported—"can be said to have been conceived by three naked men basking in the noonday California sun..." This story-telling style does more than entertain. It helps nonscientists to understand what practicing scientists know, sometimes too well: Science is a human undertaking, pursued for human motives, and limited by human failings.

The book has another commendable feature. Aimed as it is at the "popular" market, Will has to make sure he describes general relativity well enough to allow his reader to know what the tests are testing. He does this remarkably well in places, as in his explanation of why the curvature of time is responsible for the Newtonian gravitational effects, and in his analogy between the dragging of inertial frames

and water draining from a pool. By taking advantage of the fact that he is describing real experiments rather than theoretical imaginings, Will is able to guide the nonspecialist reader through some difficult ground very elegantly indeed.

Will is well qualified to write on this subject. With Kip Thorne and Ken Nordtvedt, he provided a theoretical framework within which the tests of relativity could be understood and quantitative comparisons made between competing theories. He knows the people he is writing about and has first-hand experience of many of the experiments.

The book will appeal to a wide spectrum of readers. Since it contains little mathematics, it will be accessible to interested laymen and high-school physics students, and I can recommend it wholeheartedly. But even professional physicists have something for them, because it is the only book I know that describes the experiments and their results without too much technical detail. If you want to know how relativity has fared experimentally, this is a good place to start.

But I almost forgot to give the answer to the question, "Was Einstein right?" Well, the question doesn't have a definitive answer: Every generation has to renew the tests with greater precision and invent some more, and at any time the theory could be found wanting. As Will points out, one must never take any physical theory for granted. But today, our confidence in general relativity is stronger than ever. Astronomers know this better than most; black holes would not be the "standard model" for active galaxies if the theory were in doubt. Competitor theories, such as the Brans-Dicke scalar-tensor theory, are no longer serious contenders. Einstein's esthetic criteria have provided us with a remarkably robust theory. And there is a modern lesson here, one that is well understood by high-energy theorists. We may hope that elegance, simplicity, and mathematical consistency may yet guide us to a good "theory of everything," even if some of the energies of interest are well beyond the reach of experiment today.

General Relativity

Robert M. Wald

492 pp. U. of Chicago P., Chicago, 1984.
ISBN 0-226-87032-4 \$50.00 hardcover;
ISBN 0-226-87033-2 \$30.00 paper

More than twenty years ago, general relativity reentered the mainstream of physics and there it has remained, thanks largely to problems posed in astrophysics, cosmology, and the

search for a consistent unification with quantum theory. Such a venerable and beautiful theory has naturally also developed its own set of "internal" problems that have in turn enriched other areas of theoretical physics and mathematics. Einstein's theory has withstood every observational challenge and has survived in its original form for over 70 years. Relativity theorists have made great progress in understanding both qualitative and quantitative implications of the classical theory. Furthermore, the so far unsuccessful searches for a quantum theory of gravity or a more comprehensive theory including gravity have been strongly influenced by the ideas and techniques of general relativity. One has only to think of the Kaluza-Klein theories or the currently fashionable string theories to see that more than a nodding acquaintance with metrics, connections, and curvature is required to understand the results of the fervent efforts devoted to these grand problems.

Robert Wald has given us in his truly excellent *General Relativity* a sophisticated text of manageable size that will probably be read by every student of relativity, astrophysics, and field theory for many years to come. Experienced researchers and teachers, especially the mathematically inclined, will also find it valuable—if not indispensable. The level of mathematical rigor and precision is consistently high throughout. Yet it is accessible to students largely because Wald uses an "abstract index" notation rather than the overly abbreviated notation often used in modern differential geometry. The introductory material on tensors and the mathematical appendices are of special value in bridging the gap between what is commonly taught in "mathematical physics" courses and what is required to understand the results of the past two decades on horizons, singularities, and global space-time geometry.

Besides the mathematical appendices, the book is divided successfully between "Fundamentals" and "Advanced topics." The advanced topics include black holes, quantum effects in curved space-time and many other morsels, among which almost anyone will find something to feast upon. The excellence of the expositions reflects that Wald himself has contributed significantly to the modern understanding of many of these topics. The section on fundamentals is also generally strong. I confess some disappointment in the treatment of linearized gravity, but only because I found it too brief. The treatment would be enhanced by more detail on the nuts and

bolts of gravity wave stress tensors and other such applications of approximate forms of the theory. Such material is abundant in *Gravitation* by Charles W. Misner, Kip S. Thorne, and John A. Wheeler. Indeed, I would recommend *Gravitation* and Steven Weinberg's *Gravitation and Cosmology* as companion references for a course based on Wald's new text.

JAMES W. YORK JR
University of North Carolina
at Chapel Hill

Constructing the Universe

David Layzer

313 pp. Scientific American Books
(Freeman), New York, 1985.
ISBN 0-7167-5003-1. \$29.95

Scientific American is an interesting magazine, but reading it is not without frustrations for the average scientist. I have found that I can follow articles in my own field of physics or in the earth sciences, and that I can learn a great deal from them. On the other hand, I long ago gave up even attempting to read articles in molecular biology, because they are written at a level far beyond my ability to follow. My conversations with other working scientists lead me to believe that they have a similar experience. David Layzer's *Constructing the Universe*, a book in the *Scientific American* library, shares the strengths and weaknesses of its parent publication.

As the title suggests, this is a book devoted to an explanation of the evolution of our ideas about the physical universe, with special emphasis on ideas about cosmology and cosmogony. The book is handsomely illustrated and supplied with diagrams in the manner of articles in *Scientific American*. It traces our ideas about the universe from Ptolemy and his Greek contemporaries to modern views of the Big Bang and early universe. The average physicist will, I think, have little trouble following the development of this story. He may also find that much of the historical material is both interesting and new.

In my reading, however, I found that I was continually asking myself the question "for whom is this book intended?" If it is intended as a handbook for working scientists, then the lavish illustrations and four color graphics seem out of place. If it is intended as a book for the average layman—as an introduction to the history of science—then complex mathematical concepts such as vector notation and potential energies also seem out of place. Finally, if it is intended for use as a textbook in an astronomy course, why then are there no problems or discussion ques-

tions at the end of the chapters?

I suspect that the answer to these questions is that the book is intended for the same audience that reads *Scientific American*, or rather, the subset of that audience that reads the physical science articles in *Scientific American*. For that audience this book is ideal—what would bother the average reader will not be worrisome for them. For example, Layzer spends an entire chapter discussing complex philosophical points about the role of scientific theory before he ever presents a single theory for consideration. The book will play the same role as the familiar *Scientific American* to readers—that is, it will serve as a useful reference book, a source of diagrams and illustrations to illustrate difficult points in astronomy, and as a book that will fill in the blanks in what is already a more or less complete education. If you feel the need for this sort of book in your library you could do a lot worse than buying *Constructing the Universe*.

JAMES S. TREFIL
University of Virginia

Polarized Light in Nature

G. P. Können

(translated from the Dutch by G. A. Beerling)
172 pp. Cambridge U. P., New York, 1985.
ISBN 0-521-25862-6. \$32.50

This is a visually attractive book, lavishly illustrated with color photographs, as befits its subject and its apparent intended audience—the intelligent layperson. Alas, upon reading, one soon finds that the text does not live up to the pictures; you can't judge a book by (just) its photographs. The writing style is weak, and in places discursive and repetitive—surely something must have been lost in the translation from the 1980 original.

But the drawbacks are even more fundamental. Many of the explanations are confusing or incomplete, even the more technical ones presented in the last half of the book. Few readers who do not already know the relevant physics will fully understand Können's explanation of the formation of the rainbow and Alexander's dark band, for instance, or even his explanation of polarization itself. [For atmospheric optics, readers should stick with Robert Greenler's *Rainbows, Halos and Glories* (Cambridge U. P., 1980).] Several times an "explanation" consists instead merely of a description, as for the Zeeman effect. Some phenomena are mentioned but not explained at all: Why is light from artificial satellites polarized as much as 40%?

For a book that is "the first attempt to compile a guide to polarization" (as claimed in the introduction), the refer-

SQUID INSTRUMENTATION from BTi FOR THE ULTIMATE IN SENSITIVITY



Model DBS DYNABIAS dc SQUID system

- 3×10^{-30} Joules/Hz Energy Sensitivity
- dc -50kHz Bandwidth
- $10^6 \phi_0$ /second Slow Rate
- Thin Film HYBRID SQUID™ dc Sensor
- 2 μ Henry input impedance
- Computer Controllable

The new model 40F filter option for the dc SQUID control electronics includes a sophisticated line frequency comb filter plus high and low pass filters.

THE LABORATORY STANDARD FOR ULTRA-SENSITIVE MEASUREMENTS



Model MPS measurement system

- 10^{-13} Volts
- 10^{-11} Amps/ $\sqrt{\text{Hz}}$
- $10^{-8} \Omega$
- 10^{-11} Henries
- 10^{-10} Gauss/ $\sqrt{\text{Hz}}$
- Multiple Samples
- Operation in Fields up to 9 Tesla
- ac and dc Measurements
- Real and Complex Impedances
- 0.001% Resolution in RLM mode
- Thin Film HYBRID SQUID™ rf Sensor
- Ideal for CMN Thermometry

SHE Instrumentation from Biomagnetic Technologies, inc.

4174 Sorrento Valley Blvd.
P.O. Box 210079
San Diego, CA 92121
Telephone: (619) 453-6300
Telex 697903

In Europe:

S.H.E. GmbH
Grüner Weg 83
D-5100 Aachen
West Germany
Phone: (0241) 15 50 37
Telex 832-9453

In Japan:

Niki Glass Co., Ltd.
P.O. Box 33, Takanawa
Tokyo 108,
Japan
Phone: (03) 456-4700
Telex 232-2931