Precision measurement: A unifying aspect of physics

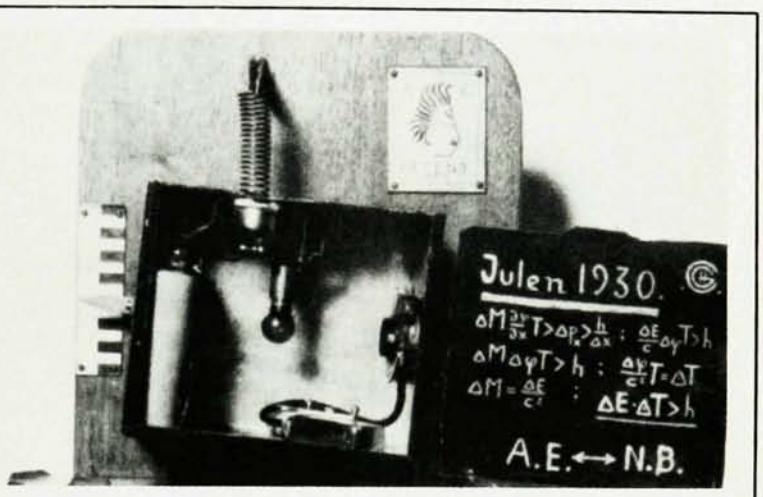
The Fundamental Physical Constants and the Frontier of Measurement

Brian W. Petley
346 pp. Hilger, Boston, 1985. $49.00
Reviewed by E. Richard Cohen

The measurement of physical quantities to the highest possible precision can be a stimulating field of endeavor if the constants being measured are properly selected. Perhaps no one cares about the density of iron to a part in a million, but the density of a silicon single crystal to even higher precision than that is important in the determination of Planck's constant. Brian Petley makes this connection, and several others, in this interesting volume. Petley is a senior scientific officer at the UK National Physical Laboratory, and over the last 20 years he has measured at least three fundamental constants himself: the proton moment, the Josephson frequency and the Rydberg constant. He is now working on the electron Compton wavelength and the proton gyromagnetic ratio. The thesis of his book is that precision measurement is a unifying aspect of physics and that measurements in one field can have surprising significance in other, initially unexpected fields. This is amply demonstrated by the awarding of the 1985 Nobel Prize in physics to Klaus von Klitzing for measuring the Sommerfeld fine-structure constant without a spectrometer or any other optical instrument except perhaps a microscope (PHYSICS TODAY, December, p. 17).

Because of the diversity of the subject matter, the book covers a broad range of physics—from the velocity of light to the local acceleration of gravity, from the electrochemical equivalent of silver to the lattice spacings of calcite and silicon. There is first of all a question of identity: What is a fundamental constant? Petley reviews some of the attempts to provide a classification; unfortunately, I have never been happy with any of them. Within the scope of this book—it is directed primarily to the problems associated with high-precision measurements, and only secondarily to the broader philosophical questions—a completely pragmatic approach would seem to be the best: A fundamental constant is a physical quantity of general significance, or one that is metrologically related to such a quantity. This "loophole" definition allows the molar mass of silicon (or, in the past, the maximum density of water) to be as much a fundamental constant as Planck's constant.

In the past 20 years the development of quantum metrology has emphasized the connection between atomic (including solid-state) physics and metrology, and the definition of the SI base units in terms of natural standards as opposed to the artifacts of the original metric system. The problem with the use of an artifact as a standard of measurement is the inability to deal with a change in the artifact itself; if there is oxidation of the standard kilogram or absorption of gas on its surface, does the unit of mass change?



George Gamow's make-believe apparatus for demonstrating Albert Einstein's *gedanken* experiment for beating the uncertainty relation on the product $\Delta E \Delta t$ by weighing a box before and after the escape of a photon, taking into account that the clock in the box will change its rate when the box moves up and down in a gravitational field, as is outlined on the cover for the box (note Gamow's anagram, imitating the one used by Gaumont). This photograph accompanies Niels Bohr's "Discussion with Einstein on epistemological problems in atomic physics," excerpted in *Niels Bohr: A Centenary Volume*, edited by Anthony P. French and P. J. Kennedy (Harvard U. P., Cambridge, Mass., 1985, $27.50). Besides this excerpt from an essay that is regarded as a classic of scientific literature, the editors have selected several other writings by Bohr, such as his Nobel lecture and essays on science and politics, the philosophy of science and nuclear physics. The bulk of the volume consists of memoirs, reminiscences and essays on Bohr and his work in atomic and nuclear physics by an impressive group of scientists and science historians, including a number of Bohr's close associates. The volume contains a chronology of Bohr's life, a glossary of terms in atomic and nuclear physics—making the book accessible to a general audience—and a bibliography of Bohr's works. (Photo courtesy of Harvard U. P., reprinted from Gamow's autobiography *My World Line* with the permission of Viking Penguin and the estate of George Gamow.)

E. Richard Cohen is at Rockwell International Science Center in Thousand Oaks, California. He was chairman of the Committee for Data in Science and Technology Task Group on Fundamental Constants from 1969 to 1985 and of the IUPAP Commission on Atomic Masses and Fundamental Constants from 1972 to 1978; he has struggled with the problems of the evaluation of the fundamental physical constants for 35 years.

Atomic standards are certainly less susceptible to these difficulties than is a Pt–Ir cylinder, but the question of the constancy of the constants (and even the question of the meaning of that question if the units of measurement are defined in terms of physical objects or phenomena that are not invariant) does not disappear.

The major part of the book is concerned with measurement and its associated problems at the level of parts per million and better, but Petley also includes a chapter on the determination of the Newtonian constant of gravitation, where he demonstrates that problems of precision can arise at the part-per-thousand level as well, and another on null experiments, in which 30% precision may be sufficient to refute the null hypothesis.

Unfortunately, the book is flawed in production; there are too many misprints and typographical errors. In a book devoted to precision I did not expect to find—on the page to which I first opened the book (page 14)—that the dimensions of the permeability of vacuum were given incorrectly. In more than one instance the spaces between words (and even the spaces between sentences) have been reduced to the point where it appears that a single word occupies the whole line. Proper names are also misspelled—"Pall" instead of "Pal" on page 44 and "Dumond" in place of "DuMond" on page 155. (These names appear correctly elsewhere in the book.) Several errors in mathematical expressions can be easily corrected by the reader with only minor inconvenience, but an apparent misunderstanding by the editor of the convention of writing the uncertainty in the final digits of a quantity in parentheses immediately following the number (for example, 1.234(5) for 1.234 ± 0.005) has resulted in the uncertainties being aligned in a separate column in the tables.

In spite of these minor annoyances, the book provides an enjoyable and concise review of a very large range of physics, and it should be read by anyone who wishes to gain an appreciation of the coherence and unity of physics and of the challenges of modern metrology.

Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles

Robert Eisberg and Robert Resnick
713 pp. Wiley, New York, 1985. $38.50

This revision of an already monumental work is over 700 pages long, not counting 19 appendices. The book conserves the flavor of the first edition while adding material on the advances of the past decade. The new chapters written by David Caldwell on elementary particles are particularly noteworthy in providing a qualitative introduction to this difficult subject.

New appendices treat topics found in more traditional quantum mechanics texts; these include time-dependent and time-independent perturbation theory, the Born approximation, series solution of the angular and radial equations for a one-electron atom, crystallography, gauge invariance, and a very nice treatment of the numerical solution of the Schrödinger equation for a square-well potential. The last-mentioned appendix includes a program in BASIC for an IBM PC; it ran without problems on my AT&T. After years of reading about how instructive it is to carry out numerical solutions to this problem, I found the authors have given us a pleasant way to go about it.

This book is truly encyclopedic, treating almost every conceivable topic in quantum physics. It is particularly commendable for the wealth of examples from different branches of physics that are worked out in the text and for the many problems found not only at the end of each chapter but also at the end of each appendix. A solutions manual for the instructor is available from the publisher.

Despite its many attractive features this book is not easy to place as a text for a course in the standard curriculum. The authors state in the preface to the first edition that the book stresses applications rather than theory and is intended for students in a terminal course in quantum theory. They feel it is equally well adapted to a course that is to be followed by a more formal course in quantum mechanics. Most undergraduate schools offer a sophomore course in atomic physics followed by a junior or senior course in quantum mechanics. The level of the book is suitable for a well-prepared sophomore, and, because it contains ample material on atomic physics, it would probably be more appropriate for use in a course in atomic physics. Alternatively, it could be used as a quantum mechanics text by chemistry or astronomy departments if the students are not planning to take quantum mechanics in graduate school. Certainly one should include this book in the reference lists for all beginning courses in quantum mechanics because the more qualitative descriptions should be quite helpful to students mired in the mathematics of traditional approaches.

Many of the results throughout the book are presented without a logical derivation because a rigorous treatment would have required too much mathematics. And sometimes the examples or notation leaves the derivations unclear or unconvincing—as in