It is a unique potpourri of historical anecdotes, philosophical arguments, mathematical derivations, and physics jargon. And it is a great bargain.

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Star Formation

Protostars and Planets II. DAVID C. BLACK and MILDRED SHAPLEY MATTHEWS, Eds. University of Arizona Press, Tucson, 1985. xx, 1293 pp., illus. $45. From a meeting, Tucson, Jan. 1984.

The transformation of an interstellar cloud to a star or a planet involves an increase in gas density by a factor 10^{25}. The range of physical problems faced by astronomers trying to understand this transformation covers a correspondingly broad spectrum, ranging from instabilities caused by galactic shock waves 10^{22} centimeters long to the coalescence of dust particles 10^{-4} centimeter in diameter. This book is a courageous attempt to bring together all the main threads in a single volume of 43 review chapters based on papers presented at a conference. Major themes discussed in the book include the instability and fragmentation of molecular clouds, the dynamics of disks and jets discovered around young stellar objects, the chemistry of meteorites and of the interstellar medium, and the origin and evolution of the giant planets and of the protoplanetary nebula.

Broadly speaking, the contributors to this volume can be identified either as astrophysicists interested in the signs of recent and incipient star formation in interstellar gas clouds 10^{20} centimeters or more distant or as planetary scientists looking within the confines of our own 10^{15} centimeter diameter solar system for clues to the origin of the sun and planets. The gap between these approaches is wide and is largely attributable to the enormous technical difficulty of detecting or studying planetary systems around any star apart from the sun. Can the gulf between the disciplines be effectively bridged in a single volume such as this? An encouraging answer comes from an examination of the differences between this volume and the proceedings of the first Protostars and Planets conference held in 1978. There are signs that the gap has narrowed considerably in the intervening six years. Because of improvements in the sensitivities of infrared and millimeter-wave telescopes, galactic astronomers are now able to study the progenitors of sunlike as well as high-luminosity stars. The success of the Voyager flybys, meanwhile, has drawn the main attention of planetary astronomers away from the terrestrial and toward the giant planets, the evolution of which bears strong resemblances to those of stars. Both groups of astronomers are faced with new problems involving the dynamics of flattened rotating systems; planetary astronomers are addressing the newly discovered complexities of Saturn's rings, while galactic astronomers are exploring the connections between collimated outflows and circumstellar disks around young stellar objects.

The editors of *Protostars and Planets II* have produced a thick volume that will be of considerably greater durability than the average collection of conference proceedings. Authors have been allowed, if not encouraged, to expand their papers into full-length reviews, which in two cases are over 90 pages long. The book is elegantly typeset and includes an extensive index, a glossary, and an 85-page list of references. A penalty for this approach is that the book has been two years in preparation. These two years have been eventful: the IRAS satellite has found dust rings around the sun and signs of planetary material around Vega, there have been flybys of Uranus and Comet Halley, and a large planet-like companion to the star van Biesbrock 8 has been discovered. It will soon be time for Protostars and Planets III.

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Precision Measurement

The Fundamental Physical Constants and the Frontier of Measurement. B. W. PETLEY. Hilger, Bristol, England, 1985 (U.S. distributor, International Publishers Service, Accord, MA). x, 346 pp., illus. $49.

Metrology and the determination of the fundamental constants are an important but little recognized field of science to which all scientists are indebted. The major participants in the field are a few individuals located principally in national standards laboratories and university laboratories who have been seduced by the "romance of the next decimal place" and who enjoy the challenge of measuring physical quantities to a higher precision with a stated uncertainty. Occasionally new science is found in the next decimal place.

Brian Petley, whose home is the National Physical Laboratory in England, is a long-time participant in this endeavor who has worked on many different metrological problems. In this book he has provided a broad survey of the field that will be useful to participants, to students, and to curious bystanders.

The first part of the book provides a historical summary discussing what is meant by a fundamental constant, the evolution of what have been regarded as fundamental constants, and the increased role in metrology of measurements of time, frequency, and wavelength. Familiar examples of fundamental constants are the speed of light, the Boltzmann constant, the Planck constant, the charge of the electron, the Rydberg constant, and the Faraday constant. The major advances in this century have been in the measurement of time and frequency and the replacement of arbitrary prototype standards, such as the distance between two scratches on a platinum-iridium bar, by standards based on the properties of simple physical systems. The second, for example, is now defined in terms of a cesium atomic clock rather than the somewhat variable rate of rotation of the earth.

Coupled with the issue of measurement is the issue of units and standards for measurement. To measure the velocity of light requires a unit for measuring length and a unit for measuring time. To measure voltage requires some form of voltmeter that has been calibrated against a standard for voltage. One shortcoming of the book is that it does not summarize the original definitions of such Standard International units as the meter, the kilogram, the second, and the ampere or provide a description of the techniques initially used to realize them. One problem that has plagued metrologists is that during this century the standards for the volt, the ampere, and the ohm have changed.

In the view of many scientists the most important constants are dimensionless constants or dimensionless combinations of constants. The most well-known example of these is the fine-structure constant that is a measure of the strength of the electromagnetic interaction. The most famous constant is the speed of light. It has been the subject of increasingly precise measurements since Galileo's first attempt to measure it using lanterns on adjacent hills. The theory of relativity elevated the speed of light to a particularly high status in that it has the same value in all inertial frames. The availability of the laser has made it possible to define the meter as the distance traveled by light in a time period measured with respect to a cesium clock. Thus the velocity of light is no longer a constant to be measured but an ingredient in the definition of the unit of length. The book deals with each of these subjects in a complete and thoughtful manner.

A similar advance has taken place with respect to electrical units in the last 20 years. The basic SI electrical unit is the ampere, and it is defined in terms of the force between two parallel current-carrying wires. It is technically difficult to realize this definition of the ampere, and for a long time it was the practice to use a standard cell for realization of the volt and a standard ohm for realization of the unit for electrical resistance. There was always a concern that these standards were not constant in time and that the standards used in geographically separated laboratories were not the same. The discovery of the Josephson effect, which describes the tunneling current between two closely proximate superconductors, has provided a unit for voltage that depends on a measurement of frequency and is much more reproducible than the standard cells used earlier. The recently discovered quantized Hall effect may provide an equally reliable standard for resistance. The author describes the recent advances pertaining to each of these units.

A subject closely related to the determination of fundamental constants is the use of precision measurements to test basic theories. The greatest effort has been devoted to measurements of the properties of elementary particles and atomic systems as tests of quantum electrodynamics. The improvements in standards and the more precise tests of theory drive one another; the tests of theories provide motivation for improvements in techniques for measurements. The book provides an excellent summary of this aspect of measurement science.

An equally important aspect concerns null experiments such as the Michelson-Morley experiment that look for deviations from the accepted theoretical framework. Examples are the validity of the inverse square force law for the Coulomb and gravitational forces, the isotropy of inertial mass, the equality of inertial and gravitational mass, the mass of the photon, the equality of the charge of the electron and the proton, the continuous creation of matter, and the constancy of the velocity of light as a function of frequency. The book provides a critical summary of the work on each of these subjects.

It is not straightforward to determine the best values for the constants from measurements since the measurements are not independent and the measured quantities depend on the several constants in a different manner. The fact that the available measurements of a given quantity may differ more than one would expect statistically from the stated uncertainties makes it advantageous to reject some measurements in a group of measurements. The book provides a summary of the methods used to obtain the best set of constants.

An essential component of a measurement is the determination of the uncertainty of the result. The last chapter provides a thoughtful and instructive discussion of this subject. Simple use of statistics is not sufficient. A good determination of the uncertainty requires insight and imagination. The history of the determination of the constants is filled with cases in which workers found that earlier work had systematic uncertainties such that new results differed by much more than would be expected if the stated uncertainty was the statistical uncertainty.

Petley gives a clear description of the manner in which most of the constants have been determined, with particular emphasis on recent developments and prospects for the future. The reviewer recommends this book to anyone interested in the subject.

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How to Solve It

Mathematical Problem Solving. Alan H. Schoenfeld. Academic Press, Orlando, FL, 1985. xvi, 409 pp., illus. $58; paper, $29.95.

A mathematics professor is asked to construct a line parallel to the base of a triangle of altitude A so as to divide the area in half. He has not done any geometry for years, and he makes three false starts before successfully constructing a line of length $A/\sqrt{2}$. The false starts waste little time, however. Two undergraduates who have received high grades in math courses are given the same problem (to solve together). They use up their allotted time on a "wild-goose chase" and fail to solve the problem even though they are at least as familiar with geometry as the professor is.

What has the professor learned that accounts for this sort of difference? Can students be taught something that will improve their problem solving in unfamiliar domains? Recent literature explains such "expert-novice" differences in terms of what Schoenfeld calls resources, such as specific knowledge of geometry and speed of accessing such knowledge. Resources, however, cannot be taught so that they transfer across domains (J. Baron, in *Thinking and Learning Skills*, vol. 2, S. Chipman, J. Segal, and R. Glaser, Eds., Erlbaum, 1985). Schoenfeld argues convincingly that resources are not the whole story. He proposes three other types of difference between those who are "mathematically sophisticated" and those who are not: heuristics, control, and belief systems.

How to Solve It, G. Polya's 1945 book on heuristics, was Schoenfeld's original inspiration. Heuristics are weak methods whose usefulness, although limited, cuts across domains: do you know a related problem you have solved before? could you solve a simpler problem? would it help to consider a special case? Schoenfeld argues that such heuristics are actually families of heuristics. If students are to be taught useful heuristics, they must be taught a hundred rather than ten. For example, there are different ways to construct "special cases," such as by substituting numbers or by assuming an additional constraint. Students must be taught when to apply each specific heuristic. (It remains to be shown, however, that sudents can in fact make better use of a specific heuristic than a general one, when both apply.) Schoenfeld also argues that heuristics will not transfer if only practice is provided. Students must also be specifically instructed in what they are doing and why it is useful. (This conclusion is consistent with other research.)

"Control" refers to the allocation of time and effort to approaches. Good control involves asking oneself (or otherwise knowing) what goal one is trying to achieve with a certain approach, how likely one is to succeed, and whether other approaches might also be appropriate. Students often undertake a difficult calculation or construction without knowing how they will use the result or whether some alternative approach might be easier.

"Beliefs" concern a student's working assumptions. For example, many students attempt to solve geometry constructions empirically, by asking whether their drawing meets the required conditions. They fail to ask whether the construction would work for other figures of the same type, and they fail to use deductive mathematical argument (of the sort used in proofs) for the purpose of discovery. They tend to think of deduction as something done only after one knows the truth, to satisfy the teacher or to play the game, rather than to discover the truth or to check a conjecture. Schoenfeld admits that there are other relevant beliefs. I would suggest that beliefs about the efficacy of thinking in general, and one's own thinking in particular, are important in mathematics and elsewhere.

The first half of the book presents this theory and illustrates it with problem-solving protocols. The rest of the book presents extensive data (and further discussion), mostly from two successful attempts to im-