ago ceased to be merely a concise procedure for cataloguing the results of observation and experiment, and the logical character of the concepts introduced is based, to an extent probably not generally appreciated, on arbitrary conventions. Probably a proper discussion of the semantics of theoretical physics cannot proceed in vague physical or philosophical terms, but will require careful definition of an underlying symbolism and terminology similar to that that has been adopted in the foundations of mathematics.

Robert D. Richtmyer
Los Alamos Scientific Laboratory

An Introduction to Scientific Research. By E. Bright Wilson, Jr. 375 pp. McGraw-Hill Book Co., Inc., New York, 1952. $6.00.

Professor Wilson has written a thoughtful book, useful both as a text for graduate students and others beginning research and as a reference for more mature and experienced researchers who wish to think over what they are doing. In fact, the words "to think over"—as applied not only to the detailed parts but to the whole pattern of a piece of research—characterize the book. If to learn from the experience of others is a mark of exceptional intelligence the researcher is here presented with a golden opportunity for intellectual gain.

The chapters are arranged more or less in the order in which the topics arise in the course of an experimental investigation, from choosing the problem to reporting the results. About half of the text should appeal directly to the common sense of the good graduate student starting research. The other half, mainly devoted to statistical design, analysis, and deduction, may be classed as uncommon sense and will require careful study and reading of references by many who are otherwise well prepared for research in their chosen fields but who have not previously concentrated on statistical matters. The exposition is clear and the author justifies his predilection for statistics by good illustrations and apt anecdotes.

Chapter 1 on "The Choice and Statement of a Research Problem" points out that many scientists owe their greatness to their wisdom in choosing problems and discusses some of the factors besides interest that should be considered both in taking on *and in abandoning* a problem. The importance of carefully stating, defining, and delimiting the problem as well as the need for maximum understanding of the subject and purpose by all concerned are stressed.

Chapter 2 on "Searching the Literature" begins with the sentence "Six hours in the library may save six months in the laboratory." A valuable check-list is given of the principal reference works, literature guides, handbooks, book lists, review journals, and abstracting journals in various scientific fields. Methods of keeping and indexing literature notes are discussed.

The third chapter, "Elementary Scientific Method", reviews the basic ideas of scientific method which are involved in practically every investigation: observation and description, cause and effect, analysis and synthesis, hypothesis, and deduction. Despite the fact that the Introduction disclaims any attempt to deal with the scientific method from the usual philosophical viewpoint and emphasizes that scientific work cannot be reduced to a routine process, philosophers should find much of interest in this book's workaday collection of principles, maxims, procedures, and techniques for the conduct of scientific research. One of Wilson's illustrious colleagues is supposed to have brushed aside all cookbook recipes for "the scientific method" by saying that it consists of nothing more than "doing one's damnedest with one's mind, no holds barred." Actually the present book is more an elaboration than a contradiction of this theme and its author would certainly be among the last to advocate research by rote!

"The Design of Experiments", Chapter 4, invites thought concerning the planning of an experiment to make sure that it is based on clear objectives, to guard against psychological bias and erroneous conclusions ("It has been conclusively demonstrated by hundreds of experiments that the beating of tom-toms will restore the sun after an eclipse."), and to obtain the maximum in pertinent results for the time, cost, and effort expended. In the latter connection the ideas of factorial design, replication, randomization, and levels of significance are introduced.

A wealth of material on "The Design of Apparatus" is outlined in Chapter 5. In these days of supported research it sometimes seems that two admonitions are insufficiently heeded: to devote design care and thought in proportion to the shop time and expense required to execute the design, and, whenever possible, to consult with the mechanician who will do the work during the design stage. Among the design items discussed are accessibility, operating convenience, null measurements, calibration, automatic recording, amplification, impedance matching, feedback and servo systems, and noise as a limitation on all measurements. Thus, the stability diagram for a feedback system is briefly explained, the expression for the mean-square displacement in generalized noise is given, and the formula for thermal noise from a resistor is neatly derived. The "almost universal unwillingness of electronics 'experts' to accept a design which has performed successfully for others" is deplored. A list of references useful to the designer of apparatus is appended.

Strong emphasis is put on keeping written records in Chapter 6, "The Execution of Experiments". This emphasis applies not only to the explicit suggestions concerning the laboratory notebook and the recording of primary data ("An experimental scientist without his notebook is off duty."), but also to plans, circuits, operating instructions, and systematic procedures in bringing an apparatus under control and in trouble shooting. A novel feature here is the listing of fourteen general "search principles" which should be useful in finding gremlins and in overcoming what some experimentalists used to call the Principle of Maximum Vexation or the Fourth Law of Thermodynamics, namely: If anything can go wrong, it will. Resolutions to do better with respect to keeping written records are, unfortunately, both as common and as fragile as new year's resolutions.

The next four chapters, 7, "Classification, Sampling, and Measurement"; 8, "The Analysis of Experimental Data"; 9, "Errors of Measurement"; and 10, "Probability, Randomness, and Logic", contain, amid a wealth of related material such as operational definitions, curve fitting, quality control, and symbolic logic, a careful exposition of the statistical point of view as applied to scientific observation, analysis, and deduction, with emphasis on the Neyman-Pearson theory and the method of confidence intervals. Not only are modern statistical methods "based on very different fundamental views from those in vogue even a decade or two ago" but it would seem that some knotty difficulties remain to be reconciled in bringing scientific practice into consonance with them.

For example: the author repeatedly and quite properly stresses the importance of avoiding personal and subconscious bias (p. 23, "often elaborate strategems must be devised to enable the observer to get the true facts recorded in his notebook"; p. 44, "the honest and enlightened investigator devises the experiment so that his own prejudices cannot influence the result. Only the naïve or dishonest claim that their own objectivity is a sufficient safeguard."). These admonitions are certainly made more difficult to follow by the requirement of statistical theory that only previously stated hypotheses may be experimentally tested; by the suggestion (p. 169) that the "analysis [of experimental data] should be carried out as soon as possible, and particularly before it becomes impossible to carry out further experiments"; and, especially, by the requirement of sequential analysis that the data be continuously analysed as they are obtained.

As the text concedes (p. 294), the requirement that "hypotheses must be stated in advance of the observations is at variance with widely used practices and has some troublesome aspects". Does this stipulation of the Neyman-Pearson theory restrict the possibility of learning something new (i.e., not thought of beforehand) from experiments? How strongly was the photoelectric equation "established" by experiments performed *before* the hypothesis was proposed? In fact, almost everyone will agree with the statement (p. 360) that "good data can easily outlast many successive theories".

These "troublesome aspects" in the attempt to squeeze the whole structure of science based on experiment and observation into the mold of existing statistical theory are perhaps symptomatic of a need for further developments. Indeed, the author expresses regret that no generally acceptable theory of scientific inference has yet been put forward and feels that a great deal remains to be done "in reducing the highly technical separate languages employed by mathematicians, philosophers, statisticians, logicians, and natural scientists to some common ground so that these groups could understand one another better".

There follow Chapter 11, "Mathematical Work", and Chapter 12, "Numerical Computations", which include, for example, brief discussions of symmetry, approximations, mathematical induction, dimensional analysis, Buckingham's π theorem, model experiments, mental arithmetic, nomographs, large and small computing machines, interpolation, and numerical methods for differentiating, integrating, and solving equations.

The last chapter, 13, "Reporting the Results of Research", reviews in ten pages the principal features of a good research report or paper. It would be useful if this chapter, or the equivalent, were read by every student beginning a research problem, and reread whenever the resolve to keep a good notebook begins to flag!

Each chapter after the first two closes with a section on notes and references; the final index seems to be unusually complete and easy to use.

It is interesting to speculate on the applicability of the principles and procedures outlined in this book to research in other fields. The pure mathematician is more concerned with the creation of concepts and the logical interrelation of ideas and less with observation and experimental data. Thus the statistical paraphernalia fall away and the strength of ideas is somehow dependent on the way they fit into a larger structure. One cannot avoid the feeling that in physics also a very essential form of research has been the creation of concepts in terms of which new laws or relations can be formulated and that the strength of a new experimental result in physics often depends on the way in which it can ultimately be related to other physical ideas as much as on the confidence intervals assigned to the particular measurements. Therefore we teach our students theoretical physics; perhaps we should, in addition, teach more statistics.

In other fields based on observation the logically connected, commonly accepted conceptual structure to which new results could be related is certainly less ramified and less developed than it is in physics and chemistry—consider, for example, the sequence: biology, medicine, psychology, sociology, political science—the statistical interpretation of data assumes progressively greater importance. Let me hasten to add that no value judgment concerning these other fields is intended: they seem so fantastically complicated that it must be next to impossible to introduce meaningful concepts sufficiently sharp for mathematical use, say, in a minimum principle or a partial differential equation.

Nevertheless, a colleague in political science has asked to borrow my copy of Professor Wilson's excellent book.

Richard A. Beth
Western Reserve University

Creep of Metals. By L. A. Rotherham. 80 pp. Institute of Physics, London, England, 1951. 15s.

The (British) Institute of Physics which "concerns itself particularly with the application of physics in industry" is publishing a series of books and booklets under the general title *Physics in Industry*. The third