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An Introduction to Scientific Research

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Exciting a Kundt's Tube with a Siren

THE remarks of Baez[1] on the Kundt's tube prompt me to add that the particle motion is made more dramatic when the tube is excited with a siren. Also the accuracy of the velocity of sound measurements is improved when this method is employed.

What may be described as cartwheels of cork dust are formed at the center of each antinode when the tube is excited in this manner. This is accomplished by adjusting the pressure and angle of the air jet. A remarkable pattern of particle motion is observed throughout the volume of the tube.

These cartwheels of dust are very thin (0.5 mm) and rotate slowly in dynamically stable motion. Thus the measurement of the wavelength is made very accurate. The frequency as determined with a siren is also more accurate than the dial readings on the usual audio oscillator. The velocity of sound can readily be determined within 1 percent of the accepted value.

The tube employed in this experiment was a glass cylinder 2.5 cm in diameter and 125 cm long. One end of the tube was closed. The siren end was covered with a card having a one-quarter inch hole. The position of the hole was adjusted with respect to the air jet to produce maximum effects within the tube.

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[1] Albert V. Baez, Am. J. Phys. 21, 64 (1953).

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ANNOUNCEMENTS AND NEWS

Book Reviews

The Classical Theory of Fields. L. LANDAU AND E. LIFSCHITZ. Translated from the Russian by Morton Hamermesh. Pp. 354+ix, 16×25 cm. Addison-Wesley Press, Cambridge, Massachusetts, 1951. Price $7.50

This is an interesting publication and will no doubt find its way into the libraries of many students of physics. The fundamentals of the mathematical techniques of field theory are well presented, so that those who are interested in this branch of physics will be able to obtain the basic concepts and techniques without having to depend heavily upon the lectures by experts and upon the original papers.

Since the subject of electrodynamics is presented from the field-theoretical point of view, this book will serve admirably as a text for an introductory course in field theory. The content and the notation are such that there will be very little difficulty in making transition to quantum field theory. However, it is rather doubtful that this book will be appropriate as an introduction to electrodynamics. In the conventional development of this subject, the experimental and the historical approach is used, i.e., the field equations are deduced from the observations by Ampere, Faraday, and others. It seems to the reviewer that the latter approach is more meaningful to a beginning student; after he has acquired a good foundation in *physical* electrodynamics, he will be able to appreciate the elegance of *formal* electrodynamics.

Also, the value of this book as a reference would have been increased manyfold had the authors indicated a few more references to original papers and other books dealing with other aspects of field theory. For example, the section on the energy-momentum tensor reminds one of a paper by W. Pauli;[1] the section on the characteristic vibrations of the field reminds one of the treatment of the classical electromagnetic field by W. Heitler.[2] References to such publications would have made it easier for students to go on to make a more nearly exhaustive study of field theory, be it classical or quantum, after having mastered the contents of this book.

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[1] W. Pauli, Revs. Modern Phys. 13, 203–232 (1941).
[2] W. Heitler, *The Quantum Theory of Radiation* (Clarendon Press, Oxford, 1936).

An Introduction to Scientific Research. E. BRIGHT WILSON, JR. Pp. 375+xiii, Figs. 53, 15.5×23.5 cm. McGraw-Hill Book Company, Inc., New York, 1952. Price $6.00.

If it requires great courage on the part of a scientist to write a treatise about his research specialty (and I am sure it does), how much greater must his courage be to attempt a treatise on how to do research in general! Such a hero or martyr (for indeed he must be both) has already put his feet and hands in the holes of the pillory and invited his enemies to snap shut the padlock!

Fortunately I am no enemy of the author of *An Introduction to Scientific Research* and indeed I feel the urge immediately to express my deep admiration for his brilliant achievement in this well arranged, well conceived and executed work of 365 pages. The explicit object of the book is "to attempt to collect in one place and to explain as simply as possible a number of general principles, techniques, and guides for procedure which successful investigators in various fields of science have found helpful." The book is stated to be "specifically intended for students beginning research and for those more experienced research workers who wish an introduction to various topics which were not included in their training."

I feel that the value of the book will be far greater for the last-named class than for beginners. In my opinion, its most outstanding feature is that it aims to acquaint scientists in general with the valuable and vital new field of mathematical statistics about which so many of us are so blissfully (nay woefully!) ignorant.

Time was, in the memory of this reviewer, when the most eminent research physicist of his day summed up his pedagogical theory as regards instruction in research in physics by saying, "Throw them in the laboratory and let them sink or swim!" Many of them sank, but then "there were giants in those days" too. A somewhat younger theoretical physicist, who in the sequel achieved easily comparable eminence also made the much quoted remark of that era, "You don't *have* to be crazy to do physics, but it helps." Nowadays, with the world split into two mortally antagonistic camps, we are coming to realize that most acute of all may be the shortage of highly trained scientific research talent and we can no longer afford the comfortable but extravagantly wasteful older hit-or-miss methods either in training that talent or in pursuing research itself.

The outstanding chapters of this book are, I believe, undoubtedly Chapter 4, "The Design of Experiments" and Chapters 8, 9, and 10 on "Analysis of Experimental Data," "Errors of Measurement," and "Probability, Randomness and Logic." In these chapters, by easy stages, the author introduces the scientist to the best and most useful new ideas that the mathematical statisticians have been developing, ideas indeed of great utility and pertinence to the research man. It is a rather disturbing fact that to date these ideas and the experts who developed them have actually been appreciated and put to work far more widely by business and industry in such fields as quality control of a mass-produced item than by the scientist who could profit so well by them to systematize and minimize his research effort. If you have never heard of the factorial design of experiments, or of significance levels, or of confidence intervals, or of randomization, or the uses of latin squares, or of fractional replication, or placebos, or of the "power" of a test, or of errors of the first and second kinds, or of sequential analysis, perhaps you have been missing something and had better read this book. I wonder, for instance, how many physicists have worried really seriously about the question as to the number of replications that are desirable or necessary in their measurements.

The famous Michelson, Pease, and Pearson experiment measuring the speed of light in a mile-long vacuum tube on the Ervine Ranch in Southern California is a case in point. Some 2885 replications of the time of transit were made with a rotating mirror over a period of three years. The base length was also repeatedly measured, *but far less frequently.* Among the *mirror* measurements, deviations from the mean as large as 30 km/sec were not uncommon and the average deviation was 10 km/sec. Because of the great number of replications a much smaller probable error (± 4 km/sec) was assigned to the grand mean, $c=299774$ km/sec, however. There is now convincing evidence from subsequent work by far superior methods that this mean value was 18 km/sec too low—a systematic error which 2885 replications did not suffice to obliterate! The distribution of the deviations was symmetric about the mean value but decidedly not Gaussian having much too widely extended wings with a sharp central core as though the measurements were taken under two distinctly different conditions, "good" and "bad." Also disturbingly large fluctuations in base length were observed which exhibited some correlation with the ocean tides.

Hindsight is much better and easier than foresight, of course, but one cannot but wonder whether the services of an astute mathematical statistician armed with some of the modern methods of sequential analysis and factorial design might not have saved a great deal of useless replication of the observations in this famous experiment which may now be said to have misled the world about its most vital fundamental physical constant for a period of twenty years.

There are gratifyingly few flaws in this text, most of these being merely faults of omission, but one exception to this is the statement in paragraph 9.8 on rejection of observations which I quote from the top of page 257. "Another, and probably better rule is to take the mean of all but the highest and lowest values." Without any specification of the number of replicate observations to which it is to apply this is extremely dangerous advice to give to neophytes in research. It is only one step away from the "fallacy of the best two out of three." Those who do not know of this pitfall are urged to get a copy of the one page note (10 cents), "The Fallacy of the Best Two Out of Three" Reprinted from the July 1949 *Technical News Bulletin* of the National Bureau of Standards. It has been shown both by experiment and theory that in a sample of only three replicate measurements, a situation in which the most outlying value is nineteen times farther from the intermediate one than is the other extreme value, has a statistical expectancy of occurring in about one out of every twelve sets! The temptation to reject even very outlying values is therefore seen to be a most dangerous one if the sample is small. A famous statistician has said (no doubt with a delightful chuckle!), "If you *must* reject data, reject that which lies closest to the mean because it has the least effect on the mean value." It is my long standing experience that young graduate students inevitably want to make their results look more coherent by rejecting outlying observations, and intuition is a very poor guide in this matter. The boundary line between honesty and dishonesty is hard to discern here and it is far safer to be very sparing about rejection. My own conviction is that the only valid reason for rejecting an observation should be knowledge, *completely independent of the magnitude of the deviation from the mean*, that some condition under which the observation was taken honestly invalidates it for use.

The section 9.11 entitled "Compounding of Errors" was distinctly disappointing in that only the formula for the error of a function, $f(x_1, x_2 \ldots x_n)$, of *observationally independent components* x_i is treated. There are many practical instances, however, when the x_i are observationally correlated (for example when the x_i are the output results of a least-squares adjustment or even more commonly when they simply consist of several numerical values with their associated probable errors or standard deviations *in whose computation certain common error contributing components have played a role*). Instances are legion where a completely incorrect error measure is assigned to a calculated function of such correlated variables because of failure to take account of the cross-product terms in the generalized propagation of error formula. One way of avoiding this pitfall is to take the trouble always to re-express the function f in terms of observationally independent quantities and to compute the standard error in f from the standard errors of these. Even this elementary precaution is not emphasized however in Dr. Wilson's text.

My experience has been that not one in ten graduate students in physics, even those who have had courses in mathematical statistics and adjustment of observations, knows how to compute the standard deviation of a weighted mean value (1) by internal consistency (based on the error measures of the individual values), (2) by external consistency (based on the deviations of the several values from their mean), and their ignorance as to the distinction between these two error measures or the significance of their ratio is equally abysmal. Another extremely common mistake is to confuse the standard deviation of a single observation with the standard deviation of the mean. Simple every-day homely considerations such as these are insufficiently emphasized in most courses and textbooks and it is a little disappointing to find that Dr. Wilson's otherwise excellent new book suffers from this same defect. The text completely omits any account of how to analyze the residues of the observational equations in a least-squares adjustment, for example, or how to compute the error measures, by external or internal consistency, of the least-squares adjusted output values. Indeed perhaps the most severe criticism that can be made of Dr. Wilson's book is that while the upper crust is well done the under crust of simple elementary principles and practices, which every college senior in the sciences ought to know but which for some reason 95 percent have not absorbed, are omitted or insufficiently emphasized. Dr. Wilson sins in very good company in this respect, however, and the prospective purchaser should not be discouraged by these remarks from making this very worth-while addition to his library.

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Heat Transfer Phenomena. R. C. L. BOSWORTH. Pp. 211 +xii, Figs. 41, Associated General Publications, Sydney, Australia (obtainable through John Wiley and Sons, Inc., New York) 1952. Price $6.00.

This volume constitutes a summary of the methods of heat transfer. Although it is too brief to be considered a treatise on the subject, the references to more detailed discussions both in physics and in engineering are so complete that the book serves a definitely useful purpose as a starting point for anyone who wishes to become familiar with some or all phases of the subject. Detailed mathematical developments are kept to a minimum and only methods of attack on a problem are given.

The descriptions are clear without the verbiage which too often makes for cumbersome reading.

In the introductory statement of Chapter 1 the author offers an explanation as to why so few physicists have bothered themselves with problems of heat transfer in their "search of an easy path to academic distinction." It is the reviewer's observation that such a path soon becomes jammed by traffic so that it no longer is easy. In Chapter 8 a discussion is given of the equivalent electrical circuit for a transport set-up, and in Chapter 9 a brief but excellent discussion of the thermodynamical similarity is given.

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Essentials of Microwaves. ROBERT B. MUCHMORE. Pp. 236+vi, Figs. 202, 18×23.5 cm. John Wiley and Sons, Inc., New York, 1952. Price $4.50.

Hand-size microwaves with interference patterns that can be measured on an ordinary ruler will in the next generation provide a concrete picture for the understanding of the propagation of light waves and radio waves.

Microwaves are the portion of the spectrum studied most recently. The physicist of this generation approaching microwaves from the field of physical optics looks for and finds the optical diffraction patterns, which, instead of being microscopic, are spread out over the table top. The transmission-line engineer brings the impedance concept into the field of microwaves. Transmission lines with their quarter- and half-wave sections that were spread over the countryside are now set up on the table top. The physicist and the transmission-line engineer hold the two handles of a nut cracker to crack microwave problems. To work together effectively they must understand each other's points of view.

Robert B. Muchmore's *Essentials of Microwaves* is designed to explain qualitatively and diagrammatically the behavior of microwaves and to present microwave techniques to the engineer who is approaching from the point of view of transmission lines and radiofrequency. It also serves to present the engineer's point of view to the physicist.

The book may be divided into three parts and read in three sittings. The first part lays a background of electricity and magnetism and electromagnetic waves in wave guides, a treatment similar to that in Simon Ramo's excellent little book, *Introduction to Microwaves*. The second part deals with the current development of tubes particularly as designed for use in the first low level stage of high gain amplifiers. The third part deals with applications of microwaves to relays, radar, electron accelerators for nuclear studies and microwave spectroscopy as a means of studying molecular structure.

The liveliest part of the book is the second or middle section, which portrays the current research on high frequency electronic tubes. In the field of physics are the