THE THEORY OF MEASUREMENTS

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PREFACE.

The function of laboratory instruction in physics is twofold. Elementary courses are intended to develop the power of discriminating observation and to put the student in personal contact with the phenomena and general principles discussed in textbooks and lecture demonstrations. The apparatus provided should be of the simplest possible nature, the experiments assigned should be for the most part qualitative or only roughly quantitative, and emphasis should be placed on the principles illustrated rather than on the accuracy of the necessary measurements. On the other hand, laboratory courses designed for more mature students, who are supposed to have a working knowledge of fundamental principles, are intended to give instruction in the theory and practice of the methods of precise measurement that underlie all effective research and supply the data on which practical engineering enterprises are based. They should also develop the power of logical argument and expression, and lead the student to draw rational conclusions from his observations. The instruments provided should be of standard design and efficiency in order that the student may gain practice in making adjustments and observations under as nearly as may be the same conditions that prevail in original investigation.

Measurements are of little value in either research or engineering applications unless the precision with which they represent the measured magnitude is definitely known. Consequently, the student should be taught to plan and execute proposed measurements within definitely prescribed limits and to determine the accuracy of the results actually attained. Since the treatment of these matters in available laboratory manuals is fragmentary and often very inadequate if not misleading, the author some years ago undertook to impart the necessary instruction, in the form of lectures, to a class of junior engineering students. Subsequently, textbooks on the Theory of Errors and the Method of Least Squares were adopted but most of the applications to actual practice were still given by lecture. The present treatise is the result of the experience gained with a number of succeeding classes. It has been prepared primarily to meet the needs of students in engineering and advanced physics who have a working knowledge of the differential and integral calculus. It is not intended to supersede but to supplement the manuals and instruction sheets usually employed in physical laboratories. Consequently, particular instruments and methods of measurement have been described only in so far as they serve to illustrate the principles under discussion.

The usefulness of such a treatise was suggested by the marked tendency of laboratory students to carry out prescribed work in a purely automatic manner with slight regard for the significance or the precision of their measurements. Consequently, an endeavor has been made to develop the general theory of measurements and the errors to which they are subject in a form so clear and concise that it can be comprehended and applied by the average student with the prescribed previous training. To this end, numerical examples have been introduced and completely worked out whenever this course seemed likely to aid the student in obtaining a thorough grasp of the principles they illustrate. On the other hand, inherent difficulties have not been evaded and it is not expected, or even desired, that the student will be able to master the subject without vigorous mental effort.

The first seven chapters deal with the general principles that underlie all measurements, with the nature and distribution of the errors to which they are subject, and with the methods by which the most probable result is derived from a series of discordant measurements. The various types of measurement met with in practice are classified, and general methods of dealing with each of them are briefly discussed. Constant errors and mistakes are treated at some length, and then the unavoidable accidental errors of observation are explicitly defined. The residuals corresponding to actual measurements are shown to approach the true accidental errors as limits when the number of observations is indefinitely increased and their normal distribution in regard to sign and magnitude is explained and illustrated. After a preliminary notion of its significance has been thus imparted, the law of accidental errors is stated empirically in a form that gives explicit representation to all of the factors involved. It is then proved to be in conformity with the axioms of accidental errors, the principle of the arithmetical mean, and the results of experience. The various characteristic errors that are commonly used as a measure of the accidental errors of given series of measurements are clearly defined and their significance is very carefully explained in order that they may be used intelligently. Practical methods for computing them are developed and illustrated by numerical examples.

Chapters eight to twelve inclusive are devoted to a general discussion of the precision of measurements based on the principles established in the preceding chapters. The criteria of accidental errors and suitable methods for dealing with constant and systematic errors are developed in detail. The precision measure, of the result computed from given observations, is defined and its significance is explained with the aid of numerical illustrations. The proper basis for the criticism of reported measurements and the selection of suitable numerical values from tables of physical constants or other published data is outlined; and the importance of a careful estimate of the precision of the data adopted in engineering and scientific practice is emphasized. The applications of the theory of errors to the determination of suitable methods for the execution of proposed measurements are discussed at some length and illustrated.

In chapter thirteen, the relation between measurement and research is pointed out and the general methods of physical research are outlined. Graphical methods of reduction and representation are explained and some applications of the method of least squares are developed. The importance of timely and adequate publication, or other report, of completed investigations is emphasized and some suggestions relative to the form of such reports are given

Throughout the book, particular attention is paid to methods of computation and to the proper use of significant figures. For the convenience of the student, a number of useful tables are brought together at the end of the volume.

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