NEW LABORATORY MANUAL OF PHYSICS

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PREFACE

THAT laboratory work is an important part of a course in elementary physics is no longer open to question. The opinion is also practically unanimous that the laboratory work should constitute an organic and integral part of the course, pursued concurrently with the instruction of the class room throughout the subject. Beyond this point, however, there is still a considerable diversity of opinion and practice within the limits of good teaching. While the author believes that this Manual will be found adapted to any approved plan of work, it will not be out of place to present the point of view from which the book was written.

Its scope is that of a laboratory guide for the pupil. It encroaches as little as possible on the province of the text-book, and does not include class-room experiments to be performed by the teacher. Many such experiments must be presented in any well-conducted course in physics; but it is unnecessary to place the directions for them in the hands of the pupils.

Every experiment in the course is a *physical* experiment. With a superabundance of excellent material within the scope of elementary physics, there would seem to be no valid reason for spending the first days in the laboratory on manipulation and measurement with vernier and micrometer calipers, the diagonal scale, the spherometer, etc., as is sometimes done, with no physics in sight.

The course aims to present a maximum of physics with a minimum of manipulation. So far as the teaching of elementary science is concerned, skill in manipulation must be regarded as a means to an end, not as an end in itself. The more simply

and directly a physical problem is presented to the pupil the better, that his thought and attention may not be diverted from the real point at issue. This principle is especially applicable in the early part of the laboratory course, where it is most frequently and most seriously violated by the use of micrometric instruments, the Jolly balance, etc., in the work on density and specific gravity, even before the pupil has had practice in the simpler methods of measuring and weighing. It would seem as if the express purpose of such work were at the outset to throw as many obstacles in the way of progress in physics as the ingenuity of teachers and instrument makers could devise.

To be entitled to a place, a laboratory experiment must serve a definite purpose in the general plan of the course; it must contribute something of value in the unfolding of that plan. Perhaps the most striking illustration of what should not be done in this respect is afforded by the familiar quantitative experiments on the breaking strength of wires and on elasticity of stretching, bending, and twisting. These experiments lead absolutely to nothing in most high-school courses. The laws with which they deal are, for the most part, not considered in elementary text-books. A simple qualitative treatment in the class room or the laboratory would serve as an ample experimental basis for all the applications that are or need be considered in a general high-school course.

The qualitative experimental study of phenomena rightly demands a large place in an elementary physics course. Economy of time and equipment, convenience, and the advantage of the superior skill of the teacher, are considerations in favor of presenting much of this material in the form of class-room experiments; but in a great many instances the laboratory experiment, affording, as it does, immediate sense perception of the phenomena in their simplest aspects and at close range, is greatly superior to any experiment viewed at a distance; and a laboratory course which fails to take this into account is necessarily one-sided and incomplete. No apology is therefore necessary

for the large number of qualitative experiments in this Manual. They are entitled to consideration. To lessen the burden of the laboratory record, which rests rather heavily on teacher and pupil alike, it is suggested that many of the qualitative experiments may be made nearly, if not quite, as valuable a part of the laboratory course without requiring a written record of them. In such cases the discussion of the observed phenomena in the recitation will suffice.

Physics should be so taught that the pupil will be led to a correct view of the significance of his laboratory work in its relation to the subject as a science. He should understand that the validity of scientific generalizations, particularly those of a quantitative character, does not depend upon the necessarily inaccurate and incomplete data gathered from the experiments of the class room and the laboratory. These experiments should be regarded as a limited inquiry into the facts at first hand, not as sources of adequate data for generalizations by the pupil, nor as "verifications" of the laws and principles stated in the text. The pupil's experiment is not a proof of the law, but an aid to the right understanding of it. For example, under Boyle's law the pupil performs an experiment with one gas only (air), at one temperature only, and with only a moderate range of pressure. With the apparatus ordinarily provided, the work is well done if it is not in error by more than two per cent. It would be no less than a complete perversion of the distinctive aims and purposes of scientific instruction to lead the pupil to regard such an experiment as a verification or proof of Boyle's law; namely, that the inverse proportionality of volume and pressure is true (*accurately* true) for all gases at any temperature and under all ranges of pressure. It is hardly necessary to say that Boyle's law is not verified until the experiment is repeated at many different temperatures with every gas, and performed with an accuracy equal to that of the ablest experimenters. It would then be found (as the texts state) that the usual statement of the law is not exact, and that it wholly fails for any gas

when near a temperature and pressure at which it liquefies. Since the pupil does not undertake such an investigation, he neither proves nor disproves the law. What he really does is to perform an experiment which, within a fair degree of accuracy, illustrates or exemplifies the law; and he does this in order that he may the better understand it, not because the law is in need of "verification."

It is of course true that the laboratory work affords a sufficient basis for important inferences and conclusions; but these are necessarily simple, and generally narrow and partial. They must be limited to what follows legitimately from the experimental data. To encourage the pupil to draw hasty and unwarranted conclusions from insufficient data is a vicious practice.

This point of view concerning the function of experimental work in elementary physics is maintained throughout the Manual, particularly in the statement of the purpose of each experiment and in the questions asked in the discussions. Consistently with the view that the laboratory course is not a sufficient basis from which to evolve physics as a science, it is assumed in the discussion of experimental results that the pupil has at least carefully read his text-book on the subject of the experiment, and is therefore in a position not only to state the conclusions which are supported by his work, but also to pass judgment on the quality of it by comparing his results with those known to be correct.

To provide opportunity for choice and to increase the adaptability of the Manual to the varying equipment of different laboratories, the number of exercises has been made considerably greater than most teachers will require in a one-year course. A course of sixty exercises, properly distributed over the different parts of the subject, would constitute a liberal provision of laboratory work, and fifty exercises a reasonable minimum. The following exercises are suggested as, on the whole, the best adapted to such a minimum course, having regard to the cost of equipment and also to the fact that many of the experiments,

or others serving the same purpose, can be performed by the teacher before the class, with satisfactory results: Exercises 1–5, 6 (any two of the four experiments), 7, 9, 10, 11 or 12, 13, 14, 16 or 17, 19 or 21, 20, 23–25, 26 (Exp. 50), 29–34, 36, any two of 37 to 41, 42, 43, 45, 47–52, 54 or 55, 56, 57–63, 64 (either experiment), 66 (any one of the experiments), 70, 73.

The experiments have been chosen and planned with due regard to a reasonable economy in the equipment of the laboratory and a moderate degree of accuracy in quantitative results. It is far better to have from two to six sets of apparatus of medium cost for each experiment, so that the entire class can be accommodated without running more than from two to four exercises simultaneously, than to provide only one set of expensive apparatus for each experiment. On the other hand, it is not a wise economy to spend money on cheap apparatus, lacking in durability and efficiency. The instruments shown in the cuts throughout the book are recommended as of satisfactory grade.

The grouping of related experiments into exercises will commend itself as a convenience both to teacher and pupil. It is intended that, in the regular progress of the work, one laboratory period (either single or double) will be devoted to each exercise. The whole of a single laboratory period will ordinarily be required for the experimental work of the exercise, with only a preliminary record of it in the form of rough notes; and time outside the laboratory must be taken for writing the permanent record. A double laboratory period (an hour and a half) should be sufficient for both the experimental work and the final record.

While the present work is in greater part a revision of the author's "Physical Laboratory Manual," it is newly written throughout; and full advantage has been taken of the opportunity to make the many improvements in subject-matter, arrangement, and presentation which have been made possible by later years of experience.

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