GENERAL PHYSICS FOR COLLEGES

BY

DAVID LOCKE WEBSTER, PH.D.
PROFESSOR OF PHYSICS IN STANFORD UNIVERSITY

HERMON W. FARWELL, A.M.
ASSISTANT PROFESSOR OF PHYSICS IN COLUMBIA UNIVERSITY

ELMER REGINALD DREW, PH.D.
ASSOCIATE PROFESSOR OF PHYSICS IN STANFORD UNIVERSITY

NEW YORK AND LONDON
THE CENTURY CO.
1923

GENERAL PHYSICS
FOR COLLEGES

PREFACE

THE last few decades have witnessed some noteworthy advances in both the science of physics and the science of education. To what extent does the average college student of physics realize this? The process of learning has received some long needed consideration, some of which invites the thought that in many ways the methods in common use have served to discourage those qualities most essential to encourage, — the interest and initiative of the student. Permanent impressions upon the mind of the student are determined largely by the strength and duration of the mental effort that he himself considers the subjects to be worth. To recognize this and to try to assist in the formulation of the estimate of value are certainly steps in advance.

If the modern student is a skeptic, who must be "shown," why should not the modern teacher accept the challenge, and with belief in his chosen subject proceed to "show." The student has a right to his position, and certainly such a state of mind is not to be ruled out of order in a scientific pursuit.

The needs of the student in this respect have perhaps received least recognition in the colleges in the subject of physics. Nevertheless, the need for new methods is probably greater in physics than anywhere else, and the opportunities for using them are ample. If a man reads a principle, say, about a body being acted upon by two forces, and has never before had his attention called to such an event, the general terms, "body" and "force," fail to suggest any mental picture, and he is lost. If he has noticed only one such event, in the diagram next to that statement on the page, he may not be lost, but he is anchored, tied to that one case, which is almost as bad as being lost, if he needs to go somewhere else. This condition can be prevented only by preparing the ground for each important principle before stating it.

This means, first showing the student some real problems from everyday things, in which he can take an intelligent interest, and next letting him see what factors in these problems are essential, so that he will see the need for some principle governing these factors and will get his mind running along the correct lines. Only after such preparation is he in a position to understand the principle and to use it. This method is after all simply a special application of the general inductive method recognized by all of us as the basis of modern research. Therefore one of our most important objects in writing this book is to make more use than heretofore of this inductive method.

It must be used not only for introducing specific principles, but even more for cultivating from the start the habit of correct thinking, thinking that is both rigorous and vigorous. The need for correct thinking may not be any greater in physics than in other pursuits, but physics offers unequaled opportunities to demonstrate that need concretely by letting the student test his methods of thought on problems where the results can be checked conclusively.

Rigorous thinking, like any new art, comes hardest at first. Therefore, as it is essential to the application of any principle of physics, or even to its correct comprehension, the treatment of the first few principles must be so thorough as to seem to a mature student almost verbose. After such a beginning, however, it is safe to make the style gradually more and more concise, so that it is possible to use the inductive method without extending the book to prohibitive length.

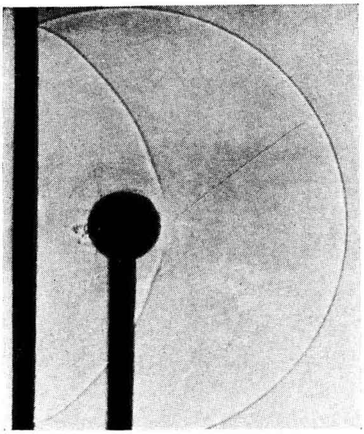
Even so, to keep within bounds we are forced to omit many topics ordinarily included in a physics text. In some respects, however, this is not wholly a disadvantage. A text should after all devote its attention primarily to the essentials, that the student must have before him, fully and readably discussed, so that he can go over them slowly and repeatedly, and get command of them, whether he learns anything else or not. Non-essential points are often very interesting, or even inspiring, and such points often make excellent material for good, live lectures. But when they are really non-essential, why should we steal the lecturer's thunder by putting them in the book?

Another point in the choice of subjects relates to the problems given out after a principle has been stated, for further practice in its application. To retain the student's interest, these, like the introductory problems, must be live ones, taken from everyday things. Such problems, which we call natural problems, are rarely quite so simple as artificial ones would be, except perhaps in electricity, where the everyday appliances themselves are all somewhat artificial. For mental training, however, one good natural problem is often worth several artificial ones, and can be treated as such in making out problem assignments, while for sustaining interest the advantage of natural problems speaks for itself. From this point of view, we have therefore made every effort to collect the best problems we can find, including those of interest to students looking forward to medicine and to engineering as well as to the student upon whom there is no pre-professional pressure.

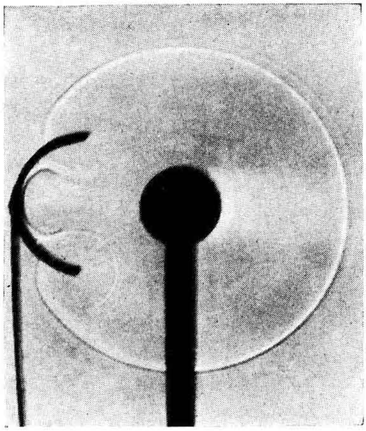
Finally, in the selection of topics, we must face the fact that men of all sorts are keenly interested in the fundamental questions of the nature of things, which we formulate nowadays under the heads of atomic structure, electron theory, quantum theory, etc. So much has been found out about these subjects in the past few years, and so many ways have appeared for making atoms and electrons real to a man without advanced mathematical training, that it will no longer suffice to add a chapter or so to the section on Electricity and a few paragraphs to Light. So we have extended our treatment of this new material to a full sized section, Modern Physics, coördinate in length and importance with Light or Electricity.

In many universities, because of the pressure of premedical or pre-engineering schedules, it may be impossible to give time to this section in proportion to the space given here. Indeed it is sure to be impossible if all the other topics in the book are to be included. Our own opinion, however, is that there are many topics which could be omitted with less real sacrifice, and our own advice is to omit some of them, each teacher making his own choice of which to omit, according to the interests and future work of the majority of his students. In case the teacher does find it necessary to omit parts of this section, our own experience with this material in a mimeographed edition, makes us confident that many students, and these the ones most worthy of the teacher's efforts, will read the whole section to satisfy their own instinct for research.

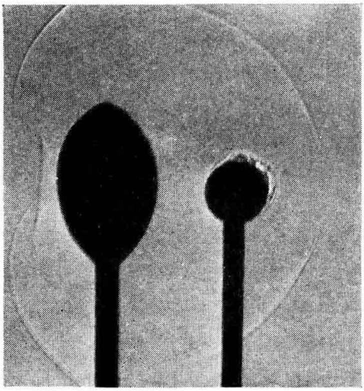
In conclusion, it is a pleasure to acknowledge that any value which the book may have is due in large measure to the help given by many colleagues and other friends, ranging from specific suggestions and corrections in the material presented to extended discussions of the more general principles, such as those outlined above. In all of these aspects, there is probably nothing essentially new in the book, but only adaptations, more or less extensive, of things done many times before.



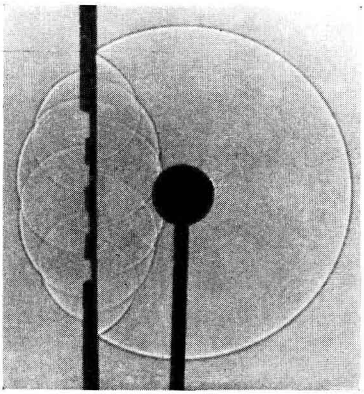
A. Plane Reflector. Wave about .0002 second after spark.



B. Cylindrical Reflector. Reflected sound wave convergent.



C. Lens of Sulphur-Dioxide Gas. Refracted wave convergent.



D. Plane Grating. Four Apertures. Wave .00016 second after spark. Huyghens's principle verified by both the reflected and the transmitted waves.

FIG. 120. — SOUND WAVE PHOTOGRAPHS (FROM PROF. A. L. FOLEY'S ORIGINALS.)

CONTENTS

PART I

MECHANICS

PART III

LIGHT

PART IV

ELECTRICITY AND MAGNETISM

PART V

MODERN PHYSICS

GENERAL PHYSICS
FOR COLLEGES

PART I

MECHANICS

CHAPTER I

WHAT IS PHYSICS?

"A SCIENCE is made out of facts, just as a house is made out of stones, but a mere collection of facts is not a science, any more than a pile of stones is a house." So said Henri Poincaré, one of the greatest mathematical physicists of the past century. If you want a mere collection of facts, go to other books than this; and if you find a book containing such a mere collection, be prepared for dull reading. Mere facts, disconnected, are sometimes of considerable value to a man who needs them in his work; for example, many such facts about a loom are valuable to a man who proposes to spend his life in a cotton mill. But to a man who intends to get ahead as an engineer, or to a non-technical man who wants to understand something about the nature of things, disconnected facts are of very little use. A real science must depend for its motive power on something else.

A few spectacular facts may appear to be exceptions to this rule. For a while, radio broadcasting holds the attention of every one, and the facts about it have an obvious interest. Ten years earlier, an airplane could keep thousands of people waiting in a grandstand for hours to see it fly; another decade back an automobile would stop all business as men watched its doubtful progress; and a decade before that a telephone was a wonderful curiosity. But nowadays, when an airplane flies over New York, hardly a man on the street turns to watch it, while as to the automobile and the telephone — does any one stop to look at them? Even these spectacular things hold our interest only so long as they make us ask, "Why?" If the telephone is not interesting today, the blame does not lie with the telephone, but with us, for failing to keep our eyes open, to ask, "Why?" and to insist on a real answer, such as physics alone can give.

Not only the telephone, but thousands of other things, illustrate this point. The electric light, the door bell, and the washing machine suggest plenty of interesting questions, typical of the thousands arising from our uses of electricity alone; a pair of spectacles, a sunset sky, and a mirage suggest some of the many interesting ones on light; and the automobile has many vital problems of heat and mechanics. Even the weather, the traditional prototype of all dull conversation, has been transformed by physicists into a most fascinating subject — fascinating, that is, to those whose eyes are open, whose minds are alert to find out about the world we are in, and to enjoy it. Physics must be approached in that state of mind, not in the state of mind of a cat that basks in the sun until driven by hunger to do something else, or of a man who kills time, his own time, out of his own life, by some temporary suicide such as a game of solitaire. To a man who is really interested in the world, a thing does not have to be spectacular to be interesting.

Nor does it need to be pleasing to the eye itself, provided one is prepared to see what is in it. If you see a steel truss bridge, and know nothing of its story, it is merely an ugly mark on the landscape. If you know a little of it, you may wonder just why some girders are large and some are small, and it begins to get interesting. If you know more, you see why, and it becomes a challenge to you, to see if you can reproduce the mental process of the man who designed it. At the same time you see its relation to countless other things of very different sorts, all governed by the same fundamental principles. The harmony of these things is inspiring, and the neat and concise way in which the principles cover all the cases lends an intangible element of beauty to even that ugly-looking structure. Thus a man who is really interested in the world "finds tongues in trees, books in the running brooks."

Ever since the human race began, men with their eyes open have asked, "Why?" — have wanted the explanations of things. But, strange to say, we have generally been content with remarkably poor explanations. And we still are so. The Greeks heard the wind whistle in the trees and asked, "Why?" Did they talk of pressure and velocity? No! It was Æolus, playing his harp. The Eskimos hear the wind howl about their huts and ask, "Why?" Do they talk of pressure and velocity? No! It is Tornarsuk, the demon of the cold, who rides the north wind and freezes men who venture out.