PHYSICS

WILLIAM F. G. SWANN

THE SCIENCES

A SURVEY COURSE FOR COLLEGES

Edited by GERALD WENDT

PHYSICS

BY

W. F. G. SWANN, D.Sc.
DIRECTOR OF THE BARTOL RESEARCH FOUNDATION
THE FRANKLIN INSTITUTE OF PENNSYLVANIA

WITH THE ASSISTANCE OF IRA M. FREEMAN, Ph.D.
ASSOCIATE PROFESSOR OF PHYSICS, CENTRAL COLLEGE, CHICAGO

THE SCIENCES

A SURVEY COURSE FOR COLLEGES

EDITED BY

GERALD WENDT, PH.D.

NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited
1941

PHYSICS

THE SCIENCES

A SURVEY COURSE FOR COLLEGES

Edited by Gerald Wendt, Ph.D.

PHYSICS
W. F. G. Swann
Bartol Research Foundation of The Franklin Institute

CHEMISTRY
Gerald Wendt

EARTH SCIENCES
J Harlen Bretz
University of Chicago

ASTRONOMY
Clyde Fisher and Marian Lockwood
Hayden Planetarium, American Museum of Natural History

BIOLOGY
Howard M. Parshley
Smith College

THE BODY FUNCTIONS
Ralph W. Gerard
University of Chicago

THE SCIENCES

EDITOR'S PREFACE TO THE SERIES

Science has many aspects, but above all it is the best use of the human intelligence to improve the conditions under which we live. In order thus to control our environment the first purpose of science must be to study and understand it. This understanding has built civilization, produced our wealth, determined many of our institutions, and has molded even our intimate outlook on life. It has become a powerful social force.

Education, on the other hand, is primarily the adjustment of each individual to his environment, thereby fitting him for a successful place in it and for a happy life. It is the simplest logic, then, to conclude that an understanding of science is an essential element in everyone's education.

Though this truth is not seriously disputed, it is nevertheless seldom that a college curriculum accords with it. The reason lies in that extreme of specialization which alone makes scientific research possible. Courses in science taught by successful specialists have for decades looked primarily toward the professional training of more specialists. This purpose has far outweighed the need of future citizens for a broad understanding of the universe and for learning the best use of the human intelligence. Technical courses in the various sciences have, indeed, long been offered to every student, but they rarely aroused his interest and seldom met his needs.

In recent years numerous efforts have been made to survey science as a whole and to present it as an integral part of a liberal education. It is not difficult to sketch the scene superficially, but the result is a smattering of descriptive knowledge which is far from being science. It is also possible to select important technical phases of each science and to ease their gravity with a froth of light words. But this too is not enough. The student and the citizen need to absorb the scientific attitude, to master the scientific method of thought, and to understand the basic concepts of the sciences. Only thus, delving beneath the superficial and avoiding the burden of the technical, can they be ready to read further and to understand in the decades to come what science is doing and can do. Only thus can their own intelligence be called into play.

Hence in this series the basis of selection is such understanding. It has been a difficult choice, for each author is keenly aware of great and important topics omitted or scantily treated. Yet condensation is mandatory. Each author in the series is a master of his own subject and each has surveyed his field from this point of view—to present what is most needed for broad understanding, to omit all that is likely to be forgotten in any case, and to prepare the student for life in the second half of the twentieth century.

Each book is an essay in itself, but the books of the series may be combined in any number and in almost any order to form a comprehensive and liberal course in science. Each contains ample suggestions for further reading.

It is apparent that the needs of college students in such a course are no different from those of any intelligent citizen in search of education, or even of college graduates seeking to fill the great gaps left in the curricula of former years. They too have questions that remain unanswered in the light, fantastic books of "popular science" and that are only aggravated by the ponderous technical textbooks. They too need the essential concepts, the method of thought and investigation, and the distinctive intellectual attitude of science.

Thus we hope that this provides the answer—a brief but significant survey of the fundamental sciences, an elementary but sound foundation for the further study, but above all a key to the understanding of our environment and of the possibilities inherent in science.

GERALD WENDT
Editor

PREFACE

A century and a half ago the domain of physics, apart from astronomy, was confined to a few unimpressive phenomena. In the brief period which has since elapsed, man has wrested from the hidden vaults of the universe more jewels in the form of new knowledge than he had gathered in the whole previous history of his civilization—jewels, moreover, of outstanding luster which have transformed the daily life of all. And, walking hand in hand with mathematics, the most logically perfect of the sciences, physics has developed a coordination and an understanding of the phenomena which are monuments to the intellectual strength of our age.

In the traditional teaching of physics, the sequence of the phenomena discussed is the order of their simplicity. Unfortunately, this sequence does not give a proper comprehension of the order of their importance. Nature has not been kind enough to render simple mathematical designs for those phenomena which are the determining factors in the physical universe. So, as in any subject, work is necessary somewhere for the student. It is my belief that work is most efficiently expended in trying to see the way in which the principles operate and how they came into existence. If the student does not get this he does not, in my judgment, get anything of value.

For one who needs physics merely as a practical tool to enable him to operate certain devices and achieve certain practical ends, the *facts* in their details as well as in their general outlines are all-important, and the *reasons* are essential only to the extent that they suffice to make use of the facts. For one who requires physics as a cultural asset, as a source of mental training, or as a prelude to original achievement, however, I venture to utter the heresy that the *ideas* are more important than the *facts*, beyond the realm in which the latter are sufficient to provide a basis for the operation of the former. Even one who intends to adopt physics as a profession will lose nothing by limiting himself in the first instance to a knowledge of only such facts as are necessary to form a basis for the ideas, leaving further knowledge of facts to grow in the friendly soil thus provided.

In astronomy, for example, one may get a superficial exhilaration by contemplating such facts as the masses of the stars, the great distances between them, and their enormous temperatures, but the mind does not find anything on which to exercise itself with permanent satisfaction until it concerns itself with the relationships between such things, or, to use the common but rather debatable expression, until it "understands" them. The process of understanding is a rather subtle one. One may listen for many months to the exposition of reasons for this and for that, arriving at a condition in which he can cite the reasons and yet feel no satisfaction in them. There is nothing that he can dispute, but there is nothing which thrills him. Then, it may be suddenly on some occasion, perhaps in contemplation of some other problem, a flash occurs in which the real significance and power of some of the "reasons" become apparent. At that instant real understanding is born; and in my judgment no understanding ever means anything until it has passed through this stage.

Everyone who finally understands has to go through processes of mind similar to those gone through by the discoverer of the theorems or principles involved. The difference between the student and the discoverer in this matter is that the latter has no animate external stimulus to accelerate the growth of new thought in his mind, whereas the student has the services of the teacher. However, I believe that in the literal sense there is no teaching, there is only *inspiration to learn or understand*. Knowledge comes from within, outwards, rather than from without, inwards. Thus the true teacher is an inner ally working in the mind of the student to break down his resistance to a discovery of the truth and slay those various influences which are continually pulling him this way and that and swaying his line of thought from the fruitful path. This book is intended as such a guide to thought.

It is a pleasure to acknowledge the very valuable help given by Dr. Ira M. Freeman in the rearrangement and condensation of the original manuscript and in writing the appendix. I am also deeply grateful to the editor and to the publishers for their patience and understanding cooperation in bringing the book into final form.

W. F. G. SWANN

SWARTHMORE, PENNSYLVANIA
July, 1941

CONTENTS

PART I

INTRODUCTION

PART II

DYNAMICS: THE STUDY OF THE MOTIONS OF BODIES

PART III

THE MAIN DIVISIONS OF PHYSICS

PART I

INTRODUCTION

PHYSICS

CHAPTER I

SCOPE AND PURPOSE OF PHYSICS

Very early in the history of mankind, people began to inquire the causes of natural events occurring in their surroundings—why the sun shone by day and vanished by night; what the stars were, and why they were grouped in the form of constellations; why water and oil possessed the ability to flow easily and take the shape of any container, while stone was hard and inflexible; what was the nature of that peculiar phenomenon of sight which revealed the presence of a mountain fifty miles away. Man wondered what the wind was—the wind which he could feel but could not see. He wondered why sucking on a tube standing in a jar of water made the water rise in the tube, and why, when a closed tube was filled with quicksilver, the quicksilver did not run out of the tube but remained standing at a certain height. He wondered why iron sank in water while cork floated. He wondered what constituted the difference between a piece of metal which pained the fingers when it was touched because, as we say, it was hot, and another piece of metal which looked just like it and yet felt quite different because, as we say, it was cold. He wondered what controlled the planets in their motions in the heavens, and what caused the tides of the ocean.

These and many other things of the kind puzzled him. The meanings of many of these phenomena have become clear to us today, but the discoveries of science continually present us with new problems. The dawn of the Electrical Age brought a new crop of puzzles. The study of light led us into new fields of mysteries whose solution was to be found only in the laws which govern the kingdom of the atom. X-rays, the radiation from radium, and now cosmic rays all conspire to present new problems to man. The study of such things, and of many others of the same general nature, and the attempt to understand them constitute the aim of the science of physics.

While from early times people had thought deeply about the universe and its laws, they had performed but few experiments to find out what those laws were. Indeed, there was a strong prejudice against doing experiments, for experiments seemed to involve tampering with nature, and to be akin to witchcraft. Such "explanations" as were attempted were likely to be founded upon occult considerations, upon the supposed characteristics and dispositions of the gods, or upon a sort of conscious desire of things to conform to certain principles which seemed to have no origin but in the brains of the philosophers. The fall of a body toward the ground was regarded as a sort of conscious expression of the body's desire to reunite with its mother earth. Viewing the matter in this way, the great Greek philosopher Aristotle concluded that the heavier the body, the stronger its power to attain its desired end, and therefore the more rapid its fall. Although no experiments had been performed to test the matter, it was believed until the middle of the sixteenth century that heavy bodies fell faster than light bodies; and even when the great Italian scientist Galileo, by dropping bodies of different weight from the top of the Leaning Tower at Pisa, demonstrated that such was not the case, there were many who preferred to believe what they had always believed rather than face the facts. They preferred to hold to their picture of how they thought things should be and to explain away the facts by invoking possible disturbing causes which prevented things from happening as they believed they should.

And so in ancient and medieval philosophy we find the "explanation" that quicksilver stands up in a tube closed at the upper end because it dislikes to leave a nothingness at the top: "Nature abhors a vacuum." There was mystery in the number seven, and that was why there are seven openings in the head —two nostrils, two eyes, two ears, and a mouth; why there are seven days in the week; why there were, according to the belief of the day, seven planetary bodies; and so on. When Galileo invented the telescope and saw with it the satellites of Jupiter, there were many who, fearful of the consequences of violating the principles inherent in the mysterious number seven by the addition of these new objects, preferred to think that the telescope lied.

To the Egyptians, the universe was a box. Around the box flowed a river. On the river was a boat, and the boat carried the sun. Later, it was argued that the circle being the perfection of symmetry, the heavenly bodies must of necessity move in circles; or, if not in circles, then in orbits compounded out of circles.

Today the physicist busies himself more with the search for the fundamental laws which govern the universe than with attempts to explain why those laws should hold. He is as one who, on discovering a new country, interests himself in its laws and their relations to one another, in the ways in which they can be made to operate for his benefit, etc., without raising the question of why those laws are as they are. He seeks to avoid to a large extent the inquiry as to why things are as they are, and devotes himself to finding out what they are.

However, it must not be supposed that the man of science is content merely to learn a number of isolated facts. He is forever trying to see how one or more facts may be regarded as a consequence of some other facts. The more he can bind the phenomena of the universe together in his mind in this way, the more he feels that he understands them. Always, however, there must be some starting points, some facts which act as primordial ancestors to all the others. Probably all readers of this book have studied elementary geometry, where, from certain axioms and postulates, a whole string of propositions and theorems is evolved as a logical consequence. The phenomena of nature are like those propositions and theorems; only, instead of having them presented in orderly sequence, the physicist has them hurled at him all mixed up, and some of them may be missing or undiscovered. It is his business to arrange them in proper order, find the missing ones, and work his way back to the logical starting points. Those starting points are the ancestors referred to above—the forefathers of all the other facts. In ancient times men preferred to design their own great-grandfather facts, rather than put up with what nature provided; and it is small wonder that the ancestors seldom fitted the progeny.

Many have hoped that when the starting points—the primordial ancestors of all the facts—were found, they would appear as obvious, as something which must be true. Alas! We now know that this hope is an illusion. There must always be some starting points to be taken for granted; and, as the science of physics has developed, the "somewhere" from which it seemed expedient to start has changed from time to time.

It was not until the advent of Galileo that the science which we call physics began to make any real progress. Galileo was the first to find a good "somewhere" from which to start.

BIBLIOGRAPHY

(The books regarded as most essential are marked with an asterisk.)

BROGLIE, LOUIS DE, *Matter and Light,* W. W. Norton and Company, New York, 1939.

EDDINGTON, A. S., *The Nature of the Physical World,* The Macmillan Company, New York, 1928.

*FREEMAN, IRA M., *Invitation to Experiment,* E. P. Dutton and Company, New York, 1940.

*HARRISON, G. R., *Atoms in Action,* William Morrow and Company, New York, 1939.

HEYL, PAUL R., *The New Frontiers of Science,* D. Appleton-Century Company, New York, 1930.

JASTROW, JOSEPH, *The Story of Human Error,* D. Appleton-Century Company, New York, 1936. (The chapter, "Error in Physics," by W. F. G. Swann.)

JEANS, SIR JAMES, *The Universe Around Us,* The Macmillan Company, New York, 1929.

JEANS, SIR JAMES, *The Mysterious Universe,* The Macmillan Company, New York, 1932.

KAEMPFFERT, WALDEMAR, *Science Today and Tomorrow,* The Viking Press, New York, 1939.

LEMON, H. B., *From Galileo to Cosmic Rays,* University of Chicago Press, 1934.

LINDSAY, R. B., *General Physics for Students of Science,* John Wiley and Sons, New York, 1940.

*LODGE, SIR OLIVER, *Pioneers of Science,* The Macmillan Company, New York, 1893.

*SWANN, W. F. G., *The Architecture of the Universe,* The Macmillan Company, New York, 1934.

*WENDT, GERALD, *Science for the World of Tomorrow,* W. W. Norton and Company, New York, 1939.

WETHAM, W. C. D., *A History of Science,* The Macmillan Company, New York, 1929.