MODERN PHYSICS

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modern physics

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Supplementary Materials For The MODERN PHYSICS Program

Modern Physics (Teacher's Edition)
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Exercises and Experiments in Physics
Tests in Physics
Alternate Tests in Physics

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The Physics of Space—Sutton
Optics—Gluck

preface

The approach to the study of an introductory course in physics has been the subject of much discussion and experimentation in recent years. The authors of MODERN PHYSICS are in close contact with these developments and have tested and evaluated numerous procedures and innovations in their own physics classes. The manuscript for this revision of MODERN PHYSICS stems from the judgment and experience of the authors and reflects the recommendations of numerous experienced physics teachers from all parts of the United States who were consulted during its preparation. The aim, as in past editions, has been to present the basic concepts of physics in a logical sequence believed to be most productive with beginning students.

A real understanding of science is always its own best motivation. No effort has been spared to present physics with a directness and simplicity which will enable each student to achieve maximum comprehension. The logical organization of topics and the thoroughly understandable prose are designed to meet the requirements of today's physics students.

Because an understanding of mechanics provides the basis for developing concepts of all physics, these fundamental areas have been developed early in the book. The kinematics and dynamics chapters have been expanded, reorganized, and rewritten. The chapters on atomic structure and nuclear reactions have been reorganized and rewritten extensively, as have the chapters dealing with heat energy, wave motion, and sound. Many other changes in organization and content have been made throughout the text. New chapters on particle physics and modern applications of physics have been added.

A consistent effort has been made throughout the text to conform to the *International System of Units* as adopted by the General Conference of Weights and Measures in 1960. Minor exceptions have been exercised where these standards were too sophisticated for beginning students. MKS units have been used generally; English units have been omitted in order to remove a synthetic complicating factor in quantitative work. The dimensional analysis techniques have been emphasized in all quantitative exercises.

The successful use of this text is based on the supposition that the student has completed at least one general science course and has received an adequate preparation in algebra and geometry. The elementary trigonometry necessary for the problem work is presented in the text proper. A *Mathematics Refresher,* preceding the Appendix Section, presents a brief review of the mathematical skills required of the average physics student.

MODERN PHYSICS abounds in instructional aids which are helpful to both the teacher and the student. New scientific terms are defined when they first appear in the text. Terms which teachers have indicated are difficult for students are pronounced phonetically. This is a practical aid for the student in mastering the *language of physics.* A complete *Glossary* of terms follows the Appendix Section.

Following the presentation of topics involving difficult quantitative relationships, one or two *Examples* are given with solutions worked out in detail. These are appropriately set off from the text and aid the student in developing a method for solving physics problems.

A uniform procedure is presented for problem solving throughout the text in which the student applies learned concepts and relationships to derive a *working equation* appropriate for the specific problem presented. This directs the student away from the barren practice of problem solving by "plug-in" methods.

At the end of each chapter there is a *Review Outline* consisting of important topics and terms presented in the chapter. This outline will be useful as a guide for study notes and mastery of vocabulary and as a basis for review before a test. Included also as a part of the activity program of each chapter (and in some chapters, of each major subdivision) are two sets of *Questions* and two sets of *Problems,* graded and differentiated as *Group A* and *Group B*. The materials in the *A* sets are planned as basic materials for *all* students. They provide essential drill exercises. Vector analysis problems in these sets are limited to right triangles and require both graphical and mathematical solutions. The *B* questions and problems are more difficult and more challenging, so as to provide for individual or group differentiation. Vector analysis problems in these sets include non-right triangles and require graphical and more sophisticated mathematical solutions. A table of trigonometric functions to half-degree values and a four-place table of logarithms are provided in *Appendix B*.

Care has been taken to use color in the diagrams wherever it will aid understanding and have functional value, and to label parts clearly. Three dimensional effects are used where pertinent. An eight-page four-color insert of photographs and line drawings has been included in Chapter 17.

The following members of the Holt School Science Advisory Board have contributed significantly in the development of this textbook by reading manuscript and offering valuable suggestions and criticisms: Dr. Victor Kirsch, Supervisor of Science Instruction, Commack U.F.S.D. 10, Commack, New York, and Mr. John Weihaupt, Science Supervisor, U.S.A.F. Institute, Madison, Wisconsin. Mr. Herbert H. Gottlieb, physics teacher at the Martin Van Buren High School, Queens Village, New York, also provided valuable criticism which the authors made use of in preparation of final manuscript.

Mr. Herbert H. Gottlieb prepared the *Tests* and *Alternate Tests in Physics* to supplement the Modern Physics program.

The authors wish to acknowledge the efforts of Mr. Felix Cooper who prepared the illustrations for the text.

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Chapter One

MATTER AND ENERGY

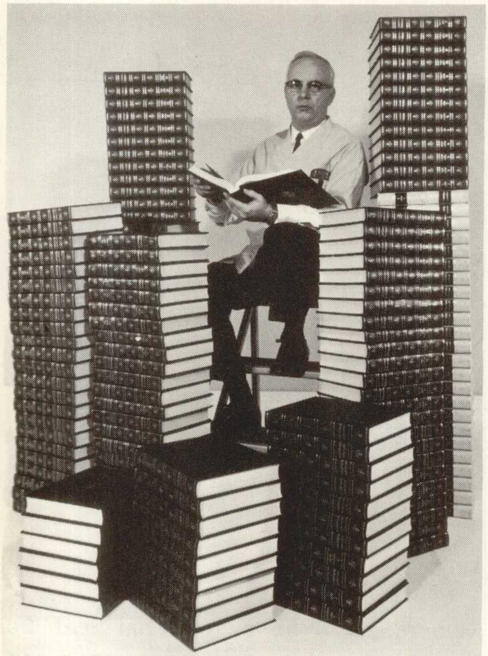
INTRODUCTION TO PHYSICS

1. Science in a modern world. It has been estimated that nine out of ten of all the scientists who ever lived are living today. So great is the need for trained men and women in this Age of Science, in fact, that our schools and colleges are often unable to meet the ever-increasing demand.

To get some idea of the vastness of today's science, browse through the periodical section the next time you visit a large library. Notice how many of the magazines are devoted to scientific subjects. Notice, too, how specialized many of the publications are. Some probably deal with areas of science that are completely strange to you. There are literally hundreds of different magazines in many different languages around the world published for the express purpose of reporting new scientific findings. The number of these periodicals is rapidly increasing.

Obviously, it is impossible for any one person to keep up with this enormous amount of new information (Fig. 1-1). A professional scientist or engineer has all he can do to keep abreast of the new developments in his own special field. For that reason, many industries engage special librarians who can help their personnel deal with this explosion of information. To do an effective job, such librarians should be trained in science and must be able to translate articles from several foreign languages as well.

Intricate technical devices and methods are also used in places where people are engaged in nonscientific work. In a supermarket, for example, you might see a customer cashing a check in front of a special camera that takes pictures of both the check and the customer to guard against fraudulent transactions. An office employee may operate a large electronic computer that performs a great many jobs with lightning speed that formerly required many hours of painstaking work. The computer can, for example, calculate the wages of all the employees and print the paychecks in a matter of minutes, provided it is given the proper instructions. On a more sophisticated level, it can analyze a firm's business to see where improvements can be made.



1-1 The information explosion. One day's output of new scientific information would fill seven sets of a large encyclopedia. (Humble Oil and Refining Company)

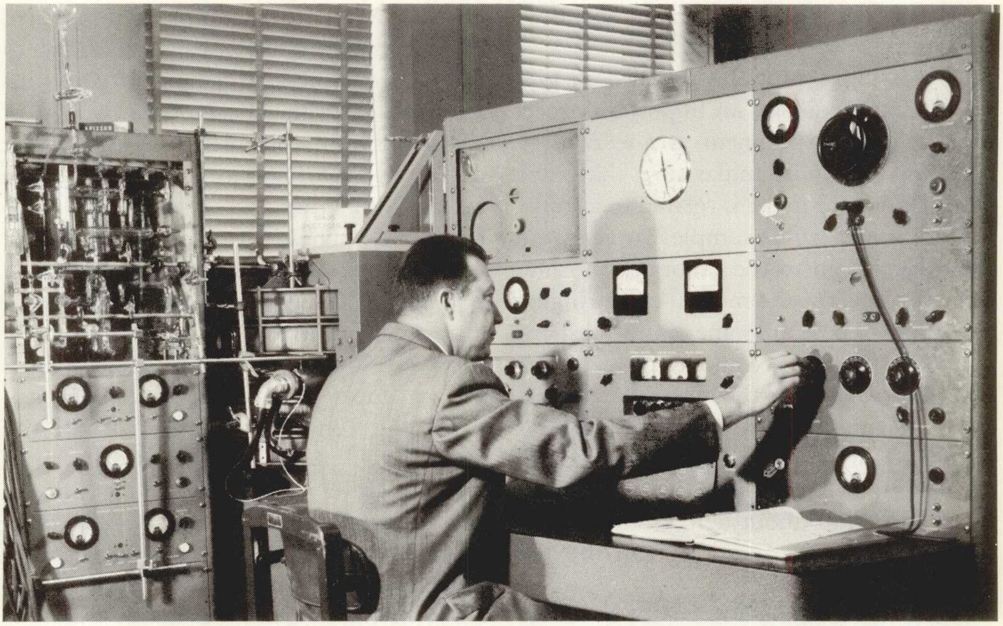
Every phase of our lives is affected by the onrush of modern science. No matter how a person makes his living today, he must get accustomed to newer and better ways of doing his job. Quite frequently, a job becomes obsolete because a machine can do it better and more cheaply. The jobholder must then be trained for a new skill. Even a scientific education quickly becomes obsolete if not constantly brought up to date. One of the most important things you will learn in this or any other course, therefore, is that education is a lifelong process, and that the attitudes and skills you acquire are more important than the facts you will be asked to remember.

Imposing as science and technology have become today, they are still tools and servants of man and not his master. Science puts powerful ideas, instruments, and methods at man's disposal, but it does not make his decisions. Science frees man from drudgery and enables him to reach for the stars, but to find purpose and direction for his life he must still look beyond science. It is well to keep this perspective as you study to take your place in our scientific world.

2. Scientific methods. **Albert Einstein** (1879–1955) was one of the greatest theoretical physicists of all time. His theories and predictions changed the course of modern science. Once he was asked to explain the way in which a scientist works. "If you want to know the essence of scientific method," he said, "don't listen to what a scientist may tell you. Watch what he does."

Similarly, if you would ask a hundred scientists to describe the methods of science, you would probably get a hundred different answers. But they would probably all agree with Einstein that science is a way of doing things, a way that involves imagination and creative thinking as well as collecting information and performing experiments. Facts by themselves are not science, but science deals with facts.

1-2 A computer installation in a modern office. (IBM)



1-3 A modern physics laboratory. Sophisticated instruments are required for research in the physical sciences. (Bell Telephone Laboratories)

The French mathematician, **Jules Henri Poincaré** (1854–1912), stated it this way: "Science is built with facts just as a house is built with bricks, but a collection of facts cannot be called a science any more than a pile of bricks can be called a house."

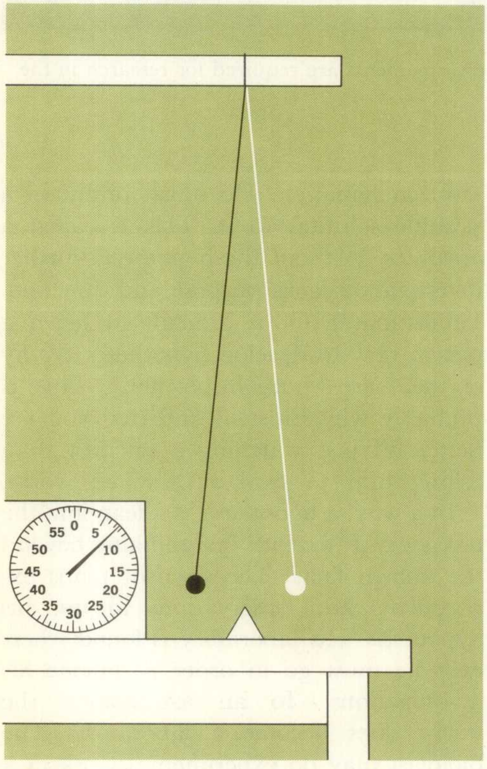
Obviously, the first thing a scientist should do when working on a project is to gather as much existing information about it as he can. This is where the library and periodicals that we spoke about before come in. Library research is a time-consuming part of the scientific method, but it is a vital part. It would be a sad thing indeed if a man were to devote years investigating a phenomenon of nature only to find that someone else had already explained it.

When the known facts about a problem are gathered, the researcher comes to the part of his investigation that requires the most imagination. He must formulate a possible solution to it. This is called a *hypothesis.* Without the hypothesis, further investigation lacks purpose and direction. Unfortunately, it is difficult to teach a person how to develop hypotheses. Many of them are "pure inspiration". That is probably why Einstein said that you are better off just watching a scientist than asking him to explain how he works.

In a way, a hypothesis is a leap into the unknown. It extends our thinking beyond the known facts. The scientist plans experiments and observations to test his hypothesis. His laboratory is found wherever he must go in order to pursue his investigations. To an astronomer, the starry skies become a laboratory. The biologist may do experimental work in a swamp or an ocean. The physicist and chemist are often surrounded by a maze of compounds and apparatus housed in buildings designed specifically for their purposes.

As you have probably learned in previous science courses, an important aspect of a science experiment is the control. That is, you must make sure that each observation you make is related to a cause. Let's take a specific example. Suppose you are asked to go to the laboratory to find out what governs the motion of a swinging pendulum. These are some of the questions that will probably come to your mind: Does the weight of the pendulum determine the time of a back-and-forth swing? Does the length of arc affect it? How about the length of the string? Is air pressure involved? What about temperature?

Each of these questions can be the basis for a hypothesis. In order to perform experiments properly, you will have to use one hypothesis at a time. If you want to investigate the effect of the weight of the pendulum, you must vary the weight of the bob during successive trials while keeping all other factors as nearly alike as possible. These constant factors in the experiment are the controls. It may even be desirable to set up an entirely separate experiment as a control.



1-4 A controlled experiment. By varying one factor at a time, the law describing the vibration of a pendulum can be deduced.

The example of the pendulum is a rather simple one. Solving it will not advance the frontiers of science because the laws of the pendulum are already well-known. However, in performing the experiment you will become familiar with the methods of science. You will also become aware (if you do the work thoughtfully) of many questions about the pendulum that did not at first occur to you. You will notice factors that should be kept constant which were not apparent when the experiment began. These may make it necessary for you to begin all over again. That is why it is often said that science raises more questions than it answers.

3. Certainty in science. When you have found the factor, or factors, that govern the motion of the pendulum, you can say that you have reached a conclusion about the pendulum. But how sure is the conclusion? In reporting it, it is important to describe your experiments carefully and to list all measurements precisely as you record them. We will discuss this part of the scientific method in greater detail in the next chapter. Anyone who reads your report must be able to understand the conditions under which the experiment was performed, because these conditions limit the certainty of your conclusions and also provide the clues for further study.

It cannot be emphasized too strongly

that the validity of a scientific conclusion is always limited by the method and the person who made it. In a sense, therefore, there is no such thing as absolute truth in science. The famous Danish physicist, **Niels Bohr** (1885–1862), used to tell his classes: "Every sentence I utter must be understood not as an affirmation but as a question."

When a scientific conclusion becomes generally accepted it is called a *law* or *principle.* Particularly in physics, laws are usually expressed as mathematical formulas. The formula is useful in describing natural events and in predicting future events. But its limits must always be kept in mind, so far as they are known. Often these limits are not even apparent to the experimenter, however, which makes it doubly important to keep an open mind about the validity of every scientific law. When a scientist becomes unwilling to question an existing principle, no matter how well established it is, he has lost one of the most important attributes of a successful researcher.

Perhaps there are still things to be discovered about the pendulum. Maybe the laws of the pendulum do not hold true beyond certain limits. Even though it is true that a single experiment can disprove a law while no amount of experimentation can ever prove one absolutely, it is a thrilling thing to push the search a little bit further on this frontier of the mind.

The methods of science have been so successful in answering questions about nature and in making life more pleasant and productive that it has been proposed that all of education should be infused with a spirit of science. This suggests that the attitudes necessary for successful work in science could bear fruit in other areas as well. Among these attitudes are: a thirst for knowledge and understanding, a questioning mind, a regard for data and their meaning, the demand for proof, a respect for logical thinking, and the willingness to work with new ideas.

4. The science of physics. The word "science" comes from a Latin word meaning knowledge. However, not all knowledge is included in the meaning of the word as it is used today. We have already seen in this chapter that knowledge must be organized and studied in a certain way before it can be termed scientific. When pursued in this way, many branches of learning are called sciences. For instance, you have already taken courses in the social sciences. Similarly, there are behavioral sciences, mathematical sciences, and others.

The study of the physical universe is called physical science. *Chemistry* is a physical science. It deals with the composition of matter and reactions between various forms of matter. *Physics* is another physical science. It is concerned with the relation between matter and energy. Since both chemistry and physics deal with matter, these two sciences overlap to some extent. Always a basic consideration in the study of physics is the idea of energy: what it is, what form it takes, how it affects matter and how matter affects it, and how it can be changed from one form to another.

It is not possible to pinpoint the beginning of physics in history, because man's concern with matter and energy is as old as man himself. The most ancient body of systematized knowledge about the forms of matter dates back to the Greeks. **Aristotle** (384–322 B.C.) taught that all things are made up of four "elements": air, earth, fire, and water. Others believed that matter could be further subdivided into tiny "atoms." Among those who held this view were **Democritus** (460–370 B.C.) and **Epicurus** (341–270 B.C.). Both viewpoints were supported by complete systems of logic, for which the Greeks were famous.

Almost 2000 years passed before the study of energy was undertaken again in an organized way. **Galileo Galilei** (1564–1642) studied the behavior of falling bodies and formulated laws describing this behavior. He also investigated the pendulum and put it to use in a clock. At about the same time, **Johannes Kepler** (1571–1630) discovered that the orbits of the planets were elliptical in shape and that their motion could be generalized in the form of a mathematical formula that could be used to predict their future motions. These same laws of Kepler are used in calculating the flight paths of today's space vehicles.

The year Galileo died, the man was born who would carry physics to unprecedented heights. **Isaac Newton** (1642–1727) developed the laws of motion and gravitation that explained the observations of many scientists who had preceded him. He also made basic discoveries concerning the nature and composition of light.

During the 18th century, a beginning was made in the scientific study of heat and electric energy. **Benjamin Franklin** (1706–1790) and **Michael Faraday** (1791–1867) did much of the pioneer work in electricity, while **Count Rumford** (1753–1814) and **James P. Joule** (1818–1889) put the study of heat on a scholarly basis.

At the beginning of the 19th century, the study of light was further advanced by the work of **Thomas Young** (1773–1829) and **Augustin Fresnel** (1788–1827). Toward the middle of the century, it became apparent that the various topics of physics (motion, light, electricity, heat, and sound) could all be described in terms of energy. With the brilliant work of **James Maxwell** (1831–1879) in electricity and

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Satellitum tempora periodica.

1d. 18h. $28'\frac{3}{5}$. 3d. 13h. $17'\frac{9}{10}$. 7d. 3h. $59'\frac{3}{5}$. 16d. 18h. $5'\frac{1}{5}$.

Diſtantiæ Satellitum à centro Jovis.

Ex Obſervationibus	1.	2	3	4	
Caſſini	5.	8.	13.	23.	Semidiam. Jovis.
Borelli	$5\frac{2}{3}$.	$8\frac{2}{3}$.	14.	$24\frac{2}{3}$.	
Tounlei *per Micromet-*	5,51.	8,78.	13,47.	24,72.	
Flamſtedii *per Microm.*	5,31.	8,85.	13,98.	24,23.	
Flamſt. *per Eclipſ. Satel.*	5,578.	8,876.	14,159.	24,903.	
Ex temporibus periodicis.	5,578.	8,878.	14,168.	24,968.	

Hypoth. VI. *Planetas quinque primarios Mercurium, Venerem, Martem, Jovem & Saturnum Orbibus ſuis Solem cingere.*

Mercurium & Venerem circa Solem revolvi ex eorum phaſibus lunaribus demonſtratur. Plenâ facie lucentes ultra Solem ſiti ſunt, dimidiatâ è regione Solis, falcatâ cis Solem; per diſcum ejus ad modum macularum nonnunquam tranſeuntes. Ex Martis quoque plena facie prope Solis conjunctionem, & gibboſa in quadraturis, certum eſt quod is Solem ambit. De Jove etiam & Saturno idem ex eorum phaſibus ſemper plenis demonſtratur.

Hypoth. VII. *Planetarum quinque primariorum, & (vel Solis circa Terram vel) Terræ circa Solem tempora periodica eſſe in ratione ſeſquialtera mediocrium diſtantiarum à Sole.*

Hæc à *Keplero* inventa ratio in confeſſo eſt apud omnes. Eadem utique ſunt tempora periodica, eædemq; orbium dimenſiones, ſive Planetæ circa Terram, ſive iidem circa Solem revolvantur. Ac de menſura quidem temporum periodicorum convenit inter Aſtronomos univerſos. Magnitudines autem Orbium *Keplerus* & *Bullialdus* omnium diligentiſſime ex Obſervationibus determinaverunt: & diſtantiæ mediocres, quæ temporibus periodicis reſpondent, non

Aaa 2 diffe-

1-5 Part of a page from Newton's book on gravitation published in 1687. The row of figures at the top gives periods of revolution of four moons of Jupiter. The table lists the orbital radii of these moons as measured by different observers. The last row of figures shows the radii as calculated from Kepler's laws of planetary motion. (New York Public Library, Rare Books Division)

magnetism, physics was further simplified into only two main parts: motion (which includes heat and sound) and electromagnetism (which includes light).

The turn of the century brought with it some unexpected surprises. The discovery of X rays and radioactivity showed that matter was not as simple as had been supposed. The speculations of Einstein about the laws of motion and the relationship between matter and energy made it necessary to reexamine the whole structure of physics. These events led scientists into an entirely new area, the study of sub-