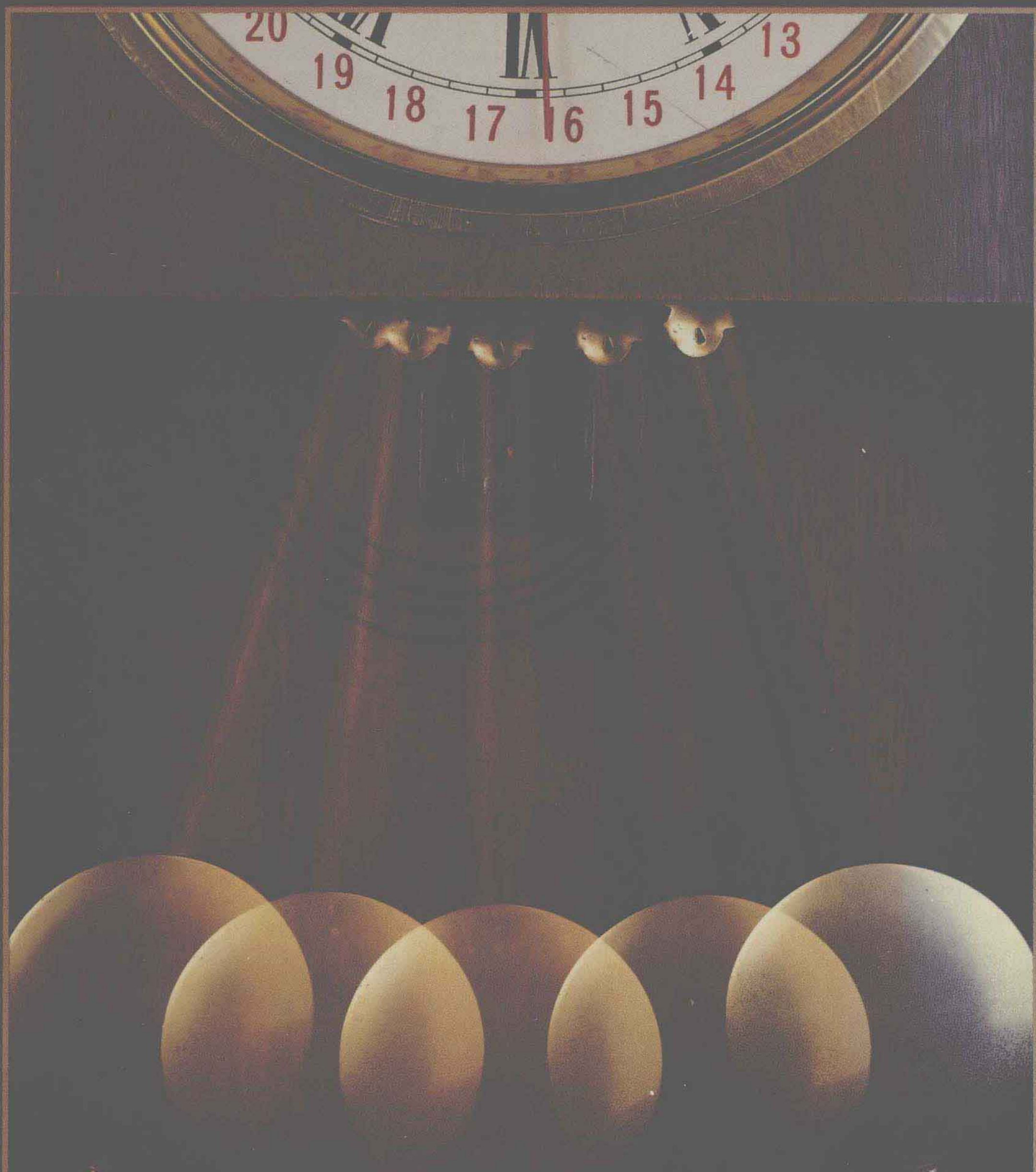
FUNDAMENTALS OF COLLEGE PHYSICS

PETER J. NOLAN



FUNDAMENTALS OF COLLEGE PHYSICS

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State University of New York
College of Technology at Farmingdale

WCB Wm. C. Brown Publishers
Dubuque, Iowa • Melbourne, Australia • Oxford, England

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Library of Congress Catalog Card Number: 91–73290

ISBN 0–697–12145–3

Printed in the United States of America by Wm. C. Brown Communications, Inc., 2460 Kerper Boulevard, Dubuque, IA 52001

10 9 8 7 6 5 4 3 2 1

This book is dedicated to my sons—Thomas, James, John Michael, and Kevin—the joy of my life.

Preface

This book is an outgrowth of over twenty-five years of teaching college physics, and it has been used in the classroom in manuscript form for some of them. Because it is written for students, it contains a great many of the intermediate steps that are often left out of the derivations and illustrative problem solutions in many traditional college physics textbooks. Students new to physics often find it difficult to follow derivations when the intermediate steps are left out. In addition, the units of measurement are carried along, step by step, in the equations to make it easier for students to understand. The book does not require calculus; the only prerequisites are high school algebra and trigonometry. In fact, a short review of trigonometry is given in chapter 2, before the discussion of the components of a vector.

This text gives a good, fairly rigorous, traditional college physics coverage. Instructors are expected to choose those topics they deem most important for the particular course. Students can read on their own the detailed descriptions found in those chapters, or parts of chapters, omitted from the course. Unfortunately, many interesting and important topics in modern physics are never covered in college physics courses because of lack of time. These chapters, especially, are written in even more detail to enable students to read them on their own. Even years after taking the course, students can read these sections for their own edification and enjoyment. This is one of the reasons that students should never sell any of their college textbooks. They are an investment for a lifetime of reference, illumination, and relaxation.

The organization of the text follows the traditional sequence of mechanics, wave motion, heat, electricity and magnetism, optics, and modern physics. The emphasis throughout the book is on clarity. The book starts out at a very simple level, and advances as students' understanding grows.

Color has been used extensively throughout, especially in the diagrams, to help students visualize the material. To standardize the colors used, each main part of the text uses a specific color scheme. This color scheme is spelled out in the Color as a Study Aid sections at the beginning of each part. On a few occasions it was necessary to depart from the standards to avoid confusion. In addition, some standard colors, like red and blue, may mean one thing in one Part but something quite different in another Part. This is unavoidable because there are not enough different colors to account for every physical quantity. However, the colors are consistent within any one Part of the book.

There are a large number of diagrams and illustrative problems in the text to help students visualize physical ideas. Important equations are highlighted to help students find and recognize them. A summary of these important equations is given at the end of each chapter.

Students sometimes have difficulty remembering the meanings of all the vocabulary associated with new physical ideas. Therefore, a section called The Language of Physics, found at the end of each chapter, contains the most important ideas and definitions discussed in that chapter.

In order to comprehend the physical ideas expressed in the theory class, students need to be able to solve physics problems for themselves. Problem sets at the end of each chapter are grouped according to the section where the topic is covered. Problems that are a mix of different sections are found in the Additional Problems section. If you have difficulty with a problem, refer to that section of the chapter for help. The problems begin with simple, plug-in problems to develop students' confidence and to give them a feel for the numerical magnitudes of some physical quantities. The problems then become progressively more difficult and end with some that are very challenging. The more difficult problems are indicated by a dagger (†). The starred problems are either conceptually more difficult or very long. However, just because a problem is starred is no reason to avoid attempting its solution. Many problems at the end of the chapter are very similar to the illustrative problems worked out in the text. When solving these problems, students can use the illustrative problems as a guide. However, students should be warned that physics cannot be learned by memorizing the exhaustive set of illustrative problems. These problems are only a guide to foster greater understanding. To facilitate setting up a problem, the Hints for Problem Solving section, which is found before the problem set in chapter 3, should be studied carefully.

Another feature of this book, which has been designed as a specific aid to problem solving, are the spreadsheet problems found at the end of the problems section in many chapters. These problems are indicated by the small computer symbol before the problem number. Instructions for their use will be found at the end of the A Special Note to the Student section.

A series of questions relating to the topics discussed in the chapter is also included at the end of each chapter. Students should try to answer these questions to see if they fully understand the ramifications of the theory discussed in the chapter. Just as with the problem sets, some of these questions are either conceptually more difficult or will entail some outside reading. These more difficult questions are also indicated by a dagger (†).

A word about units. Many recent college physics texts use only the International System of Units (SI units). Although working exclusively in SI units is a desirable goal, we do live in a world where other systems of units, particularly the British engineering system, are continuing to be used. Failure to show students how to work with these other units, or how to solve problems regardless of the units employed, does them a disservice. In addition, from the point of view of pedagogy, it is beneficial in the learning process to build on knowledge already possessed by students. For example, when we say a car is moving at 55 miles per hour, students immediately have a feel for this motion. With time, they will have that same feel for the car moving at 88.6 km/hr. Hence, both systems of units are found at the beginning of this book. As we progress through the book, however, the emphasis switches to the SI units, until, from about chapter 16 on, the SI units are used almost exclusively. This approach weans students from the British engineering system to the International System (SI) of units, and at the same time prepares students to convert to any unit or system of units when necessary.

The levels of college physics courses vary greatly, depending on the backgrounds of the students and the institution where the course is taught. Some instructors like to introduce the concepts of vector multiplication in the chapter on vectors and utilize these concepts throughout the course. Others feel that this introduces unnecessary mathematical difficulties. To satisfy both instruction preferences, vector multiplication is found in appendix F and can be used throughout the book if desired.

Scattered throughout the text, at the ends of chapters, are sections entitled "Have you ever wondered . . . ?" These are a series of essays on the application of physics to areas such as meteorology, astronomy, aviation, space travel, the health sciences, the environment, philosophy, traffic congestion, sports, and the like. Many students are unaware that physics has such far reaching applications. These sections are intended to engage students' varied interests but can be omitted, if desired, without loss of continuity in the physics course.

The relation between theory and experiment is carried throughout the book, emphasizing that our models of nature are good only if they can be verified by experiment.

Concepts presented in the lecture and text can be well demonstrated in a laboratory setting. *Experiments In Physics,* a laboratory text by Peter Nolan and Raymond Bigliani, is available through Burgess Publishing Company, Minneapolis, Minn.

Alternatively, your WCB Sales Representative can arrange to have your department's own lab exercises published through WCB Custom Services Division.

A Bibliography, given at the end of the book, lists some of the large number of books that are accessible to students taking college physics. These books cover such topics in modern physics as relativity, quantum mechanics, and elementary particles. Although many of these books are of a popular nature, they do require some physics background. After finishing this book, students should be able to read any of them for pleasure without difficulty.

Finally, we should note that we are living in a rapidly changing world. Many of the changes in our world are sparked by advances in physics, engineering, and the high-technology industries. Since engineering and technology are the application of physics to the solution of practical problems, it behooves every individual to get as much background in physics as possible. *You can depend on the fact that there will be change in our society. You can be either the architect of that change or its victim, but there will be change.*

Acknowledgments

I would like at this time to thank Eileen and my children for their love, understanding, patience, and encouragement throughout the long stages of writing and rewriting this book. I would also like to thank the following individuals for their encouragement: Dr. Lloyd Makarowitz, Chairman of the Physics Department at SUNY Farmingdale; Linda Rennie, our secretary; and all the members of the Physics Department at SUNY Farmingdale.

I would also like to thank all the very friendly and helpful people at Wm. C. Brown Publishing Company who helped in the production of this book. In particular, I would like to thank Developmental Editor Lynne Meyers. I would like to thank Jerry Hopper and all his people at Diphrent Strokes, Inc., who entered the realm of high technology and did all the beautiful artwork on computers. This will certainly be the way of the future. I would like to give a very special thank you to Pat Steele for the magnificent job of copy editing this book. Her help was indispensable. I would also like to thank the following individuals for their contribution to the overall text package: *Student Study Guide* by Lewis O'Kelly, Memphis State University; *Student's Solutions Manual and Instructor's Solutions Manual* by Ronald Cosby, Ball State University, Joel Levine, Orange Coast College, and Paul Morris, Abilene Christian University; *Test Item File* by Lloyd Makarowitz, *SUNY*-Farmingdale; Spreadsheet Problems by Morton Seitelman, *SUNY*-Farmingdale. Finally, I wish to acknowledge and thank the following reviewers for their helpful criticisms and suggestions: Joel M. Levine, Orange Coast College; Russell A. Roy, Santa Fe Community College; Paul Morris, Abilene Christian University; C. Sherman Frye, Northern Virginia Community College; Franklin Curtis Mason, Middle Tennessee State University; Franklin D. Trumpy; Des Moines Area Community College; Lewis B. O'Kelly, Memphis State University; Ronald M. Cosby, Ball State University; Paul Feldker, Florissant Valley Community College; J. W. Northrip, Southwest Missouri State University; Michael J. Matkovich, Oakton Community College; Michael K. Garrity, St. Cloud State University; and Phyllis A. Salmons, Embry-Riddle Aeronautical University.

A Special Note to the Student

"One thing I have learned in a long life: that all our science measured against reality, is primitive and childlike—and yet it is the most precious thing we have."

Albert Einstein
as quoted by Banesh Hoffmann in
Albert Einstein, Creator and Rebel

The language of physics is mathematics, so it is necessary to use mathematics in our study of nature. However, just as sometimes "you cannot see the forest for the trees," you must be careful or "you will not see the physics for the mathematics." Remember, mathematics is only a tool used to help describe the physical world. You must be careful to avoid getting lost in the mathematics and thereby losing sight of the physics. When solving problems, a sketch or diagram that represents the physics of the problem should be drawn first, then the mathematics should be added.

Physics is such a logical subject that when a student sees an illustrative problem worked out, either in the textbook or on the blackboard, it usually seems very simple. Unfortunately, for most students, it is simple only until they sit down and try to do a problem on their own. Then they often find themselves confused and frustrated because they do not know how to get started.

If this happens to you, do not feel discouraged. It is a normal phenomenon that happens to many students. The usual approach to overcoming this difficulty is going back to the illustrative problem in the text. When you do so, however, do not look at the solution of the problem first. Read the problem carefully, and then try to solve the problem on your own. At any point in the solution, when you cannot proceed to the next step on your own, peek at that step and only that step in the illustrative problem. The illustrative problem shows you what to do at that step. Then continue to solve the problem on your own. Every time you get stuck, look again at the appropriate solution step in the illustrative problem until you can finish the entire problem. The reason you had difficulty at a particular place in the problem is usually that you did not understand the physics at that point as well as you thought you did. It will help to reread the appropriate theory section. Getting stuck on a problem is not a bad thing, because each time you do, you have the opportunity to learn something. Getting stuck is the first step on the road to knowledge. I hope you will feel comforted to know that most of the students who have gone before you also had these difficulties. You are not alone. Just keep trying. Eventually, you will find that solving physics problems is not as difficult as you first thought; in fact, with time, you will find that they can even be fun to solve. The more problems that you solve, the easier they become, and the greater will be your enjoyment of the course.

Spreadsheet Problems

The following is a guide to using the spreadsheet problems found at the end of many chapters. In its most basic form, a spreadsheet allows one to enter data into "cells" and through programmed formulas/rules, it calculates an answer. Additionally, a spreadsheet may be used as an interactive software tool to explore "what if" type questions, such as What if gravity were doubled? What if the speed of light were halved?

Thus, the spreadsheet is an ideal physics learning and teaching tool. You can check your answers, use it to solve similar problems by changing the given values, explore variations on your own, and have the computer graph your calculated results. The recalculations of results and graphs are virtually instantaneous.

In designing the physics problem spreadsheets, the concepts have been kept relatively simple. However, since the spreadsheet was originally designed as a business tool, we must first discuss some conventions that are utilized:

1. The spreadsheet does not use subscripts or superscripts. Therefore, the mass M_1 will be written on the spreadsheet as M1. A mathmetical term such as x^2 is written as x^2.

2. Since superscripts are not used, powers of ten that are used in scientific notation are written with the capital letter E. Hence, the number 342 would be written in scientific notation as 3.42×10^2 in the textbook but would be written as 3.42E+2 in spreadsheet notation.
3. Because the spreadsheet cannot display Greek letters, symbols like θ or λ are expressed in terms of other letters such as x or w.

Additional conventions that we use in the spreadsheets are

1. All problems are done in the International System of Units (SI).
2. All angles in problems are expressed in degrees (the spreadsheet actually computes angles in radians).
3. All answers to problems are given to 2 places past the decimal point, and in scientific notation when needed.
4. The spreadsheets are "protected" by allowing you to enter data only in the designated cells (different color on color monitors).

If the results of your "creative explorations" on the spreadsheet are unintelligible, think about algebraic reality. Did you divide by zero? Are the numbers too large?

To use these spreadsheets you must know how to "boot" a PC or PC compatible and load the spreadsheet program Lotus 123. Your instructor, a computer lab assistant, or a friendly "hacker" will assist you in doing this.

Once you are in Lotus 123 with a blank spreadsheet in front of you, insert the floppy disk which contains the problems into the floppy drive (A) and type /FRA: (/ gives the command line, F for file, R for retrieve, A: for from the A drive) and then press the "Return" or "Enter" key. By using the arrow keys, you may highlight the chapter whose problem(s) you wish to retrieve, and then press return.

A spreadsheet has boxes called cells that are referenced by a letter, which designates the vertical column, and a number, which designates the horizontal row. In this notation, for example, C5 is the cell that is found in column C in the fifth row. You move about the spreadsheet using the arrow keys. By pressing the "Home" key, the cursor will always jump to cell A1 no matter where the cursor is presently located on the spreadsheet. Some chapters have more than one problem on the same spreadsheet. Just move the cursor down the sheet and you will find them.

To enter data into a cell, highlight the cell by moving to it using the arrow keys. (Notice that the upper left-hand corner of the screen displays the cell location.) Now enter the data value and then press the return key. The number can be entered in "normal" or scientific notation, in some cases the spreadsheet will convert it to scientific notation for you. Notice that the answers are displayed and changed almost immediately.

If the spreadsheet contains a graphic, you can view its display of your data by pressing the F10 key. To return to the spreadsheet's ready mode (upper right screen message) press any key on the keyboard.

If you would like to save the spreadsheet with your new data, type /FS (command, file, save), check the A drive, then type in the new file name, and press return.

As you explore each spreadsheet's cell, its contents will be displayed in the top screen line. Much can be learned from examining the formulas that drive the calculations located in these cells. Since this is a supplemental physics tool and not a Lotus 123 course, those of you who may be wondering how Lotus works, might consider taking a computer workshop in Lotus. Lastly, these instructions have been intentionally kept to a minimum since the physics spreadsheets are hands-on computer tools that require your active participation. With minimal instruction, the average student should be up and running in about 5 to 10 minutes.

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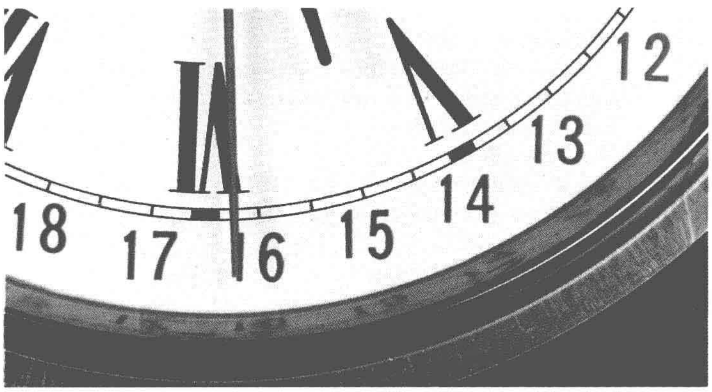

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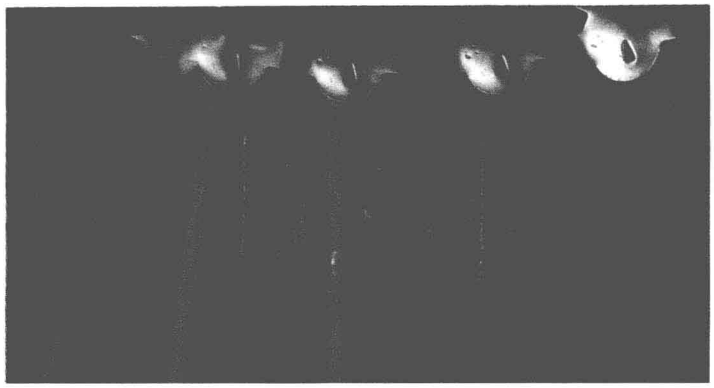

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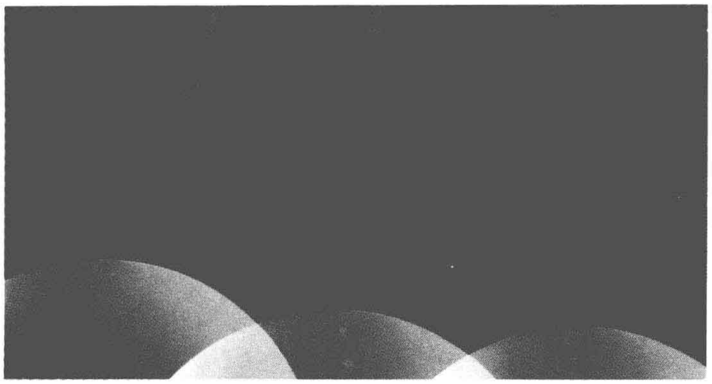

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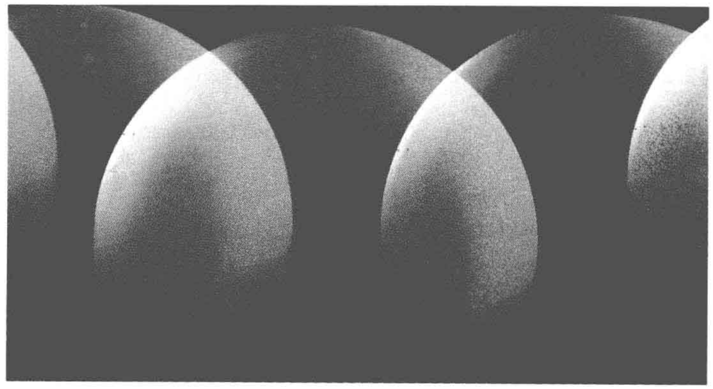

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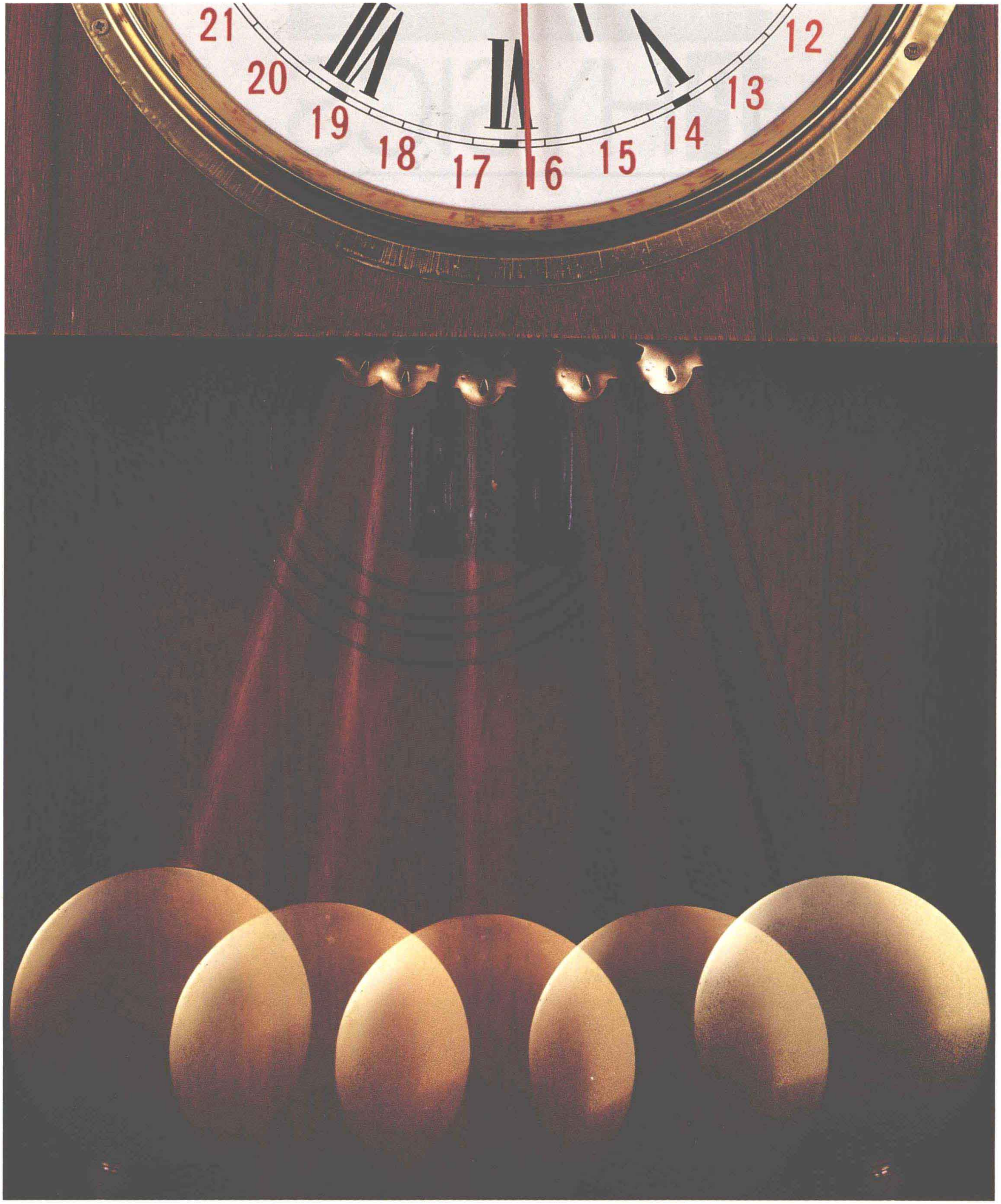
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Mechanics

PART 1

Color as a Study Aid

As a pedagogical aid, color has been extensively used throughout the book. The purpose of the color is not just to make the book look good, but rather to help the student visualize the material. The colors have been standardized according to the following code.

Chapter 2

For multiple vectors in a diagram each vector has a different color:

- First vector **a**
- Second vector **b**
- Third vector **c**
- Fourth vector **d**
- Resultant vector **R**
- Negative of a vector

The components of a vector are always a lighter shade of the same color of the original vector:

- Vector **a**
- *x*- and *y*-components of **a**
- Vector **R**
- *x*- and *y*-components of **R**

The *x*, *y*, and *z* coordinates are always black.

Chapter 3

The color code for vectors:

- Displacement vectors
- Velocity vectors
- Acceleration vectors
- Trajectories

The components of a vector are always a lighter shade of the same color of the original vector:

- Displacement vectors
- Components of displacement vector
- Velocity vectors
- Components of the velocity vector
- Acceleration vectors
- Components of the acceleration vector

Coordinates are always black.

Chapter 4

Color code for force vectors:

- Applied force vectors
- Components of applied force vector
- Tension force vectors
- Components of tension force vector
- Friction force vectors
- Normal force vectors
- Weight force vectors
- Components of weight force vector
- Reaction force vectors
- Centripetal force vector

Note that a different shade of green is used for the centripetal force vector so that it is not the same dark green that is used for the applied force vector.

Also note that a different shade of dark blue is used for the weight force vector so that it is not the same blue that is used for the velocity vector.

Chapter 5

The same color code is used as in the previous chapters. In addition:

- Lever arms

Chapter 6

The same color code is used as in the previous chapters. In addition:

- Arc *s* of a circle
- Circular orbits
- Elliptical orbits
- Gravitational force vector

Note that this is the same color as the dark blue of the weight vector.

Chapters 7 through 9

In all these chapter the same color code is used as in the previous chapters.