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MECHANICS AND HEAT, ADVANCED EDITION

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PREFACE

I GENERAL INTRODUCTION

The Mechanical Universe is a project that encompasses fifty-two half-hour television programs, two textbooks in four volumes (including this one), teacher's manuals, specially edited videotapes for high school use, and much more. It seems safe to say that nothing quite like it has been attempted in physics (or any other subject) before. A few words about how all this came to be seem to be in order.

Caltech's dedication to the teaching of physics began fifty years ago with a popular introductory textbook written by Robert Millikan, Earnest Watson, and Duane Roller. Millikan, whose exploits are celebrated in Chapter 8 of this book, was Caltech's founder, president, first Nobel prizewinner, and all-around patron saint. Earnest Watson was Dean of the Faculty, and both he and Duane Roller were distinguished teachers.

Twenty years ago, the introductory physics courses at Caltech were taught by Richard Feynman, who is not only a scientist of historic proportions, but also a dramatic and highly entertaining lecturer. Feynman's words were lovingly recorded, transcribed, and

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published in a series of three volumes that have become genuine and indispensable classics of the science literature.

The teaching of physics at Caltech, like the teaching of science courses everywhere, is constantly undergoing transition. Caltech's latest effort to infuse new life in freshman physics was instituted by Professor David Goodstein and eventually led to the creation of *The Mechanical Universe*. Word reached the cloistered Pasadena campus that a fundamental tool of scientific research, the cathode-ray tube, had been adapted to new purposes, and in fact could be found in many private homes. Could it be that a large public might be introduced to the joys of physics by the flickering tube that sells us spray deodorants and light beer?

As the idea of using television to teach physics started to reach serious proportions, a gift was announced by Walter Annenberg, publisher and former U.S. Ambassador to Great Britain, to support the use of broadcast means for teaching at the college level. Ultimately, nearly $6 million of funds from the Annenberg School of Communications to the Corporation for Public Broadcasting through the Annenberg/CPB Project would be spent in support of *The Mechanical Universe*. That, in brief, is the story of how *The Mechanical Universe* came to be.

II PREFACE FOR STUDENTS

Most chapters of this book corresponds to programs in the television series *The Mechanical Universe*, as indicated in the table on pp. xv–xvi. The television series is primarily intended for students who are not preparing (as we assume you are) for careers in science and engineering. However, our experience is that even our most sophisticated professional colleagues greatly enjoy these programs. The purpose of this book is to make it possible for you to enjoy the combined benefits of a rigorous training in physics and the less demanding pleasures of the television programs.

Although many important ideas in this course are presented in the television series, they cannot be learned by simply watching television any more than they can be learned by simply listening to a classroom lecture. Mastering physics requires the active mental and physical effort of asking and answering questions, and especially of working out problems. The examples interspersed through every chapter and the problems at the end of each chapter are intended to play an essential role in the process of learning.

The backbone of *The Mechanical Universe* is a series of events that began in 1543 with a book published by Copernicus and culminated a century and a half later with a view of the universe that, consciously or not, has formed the basis of virtually all human intellectual activity since then. It is our firm view that a thorough understanding of that revolution in human thought is essential to any serious education. Offering that knowledge in an innovative way is the purpose of *The Mechanical Universe*.

III PREFACE FOR INSTRUCTORS AND ADMINISTRATORS

We expect that the ways in which *The Mechanical Universe* television series and textbooks are used will vary widely according to the circumstances and preferences of the institutions that offer it as a college course. The television programs can be viewed at home via broadcast or cable, presented in class, offered for viewing at the student's convenience

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at campus facilities, or even dispensed with altogether. However, we hope that no institution will imagine that the course can be presented without the services of live, flesh-and-blood college physics teachers. For most students, physics cannot be learned from a book alone, and it cannot be learned from a television screen either.

No laboratory component is offered as a part of *The Mechanical Universe* project. The reason is not that we judge a physics laboratory course to be unimportant or uninteresting, but rather that we judge its presentation by us to be impractical. We expect each institution offering the course to decide how it wishes to handle the laboratory component of learning physics.

The purpose of this volume is to make it possible for students majoring in science and engineering to enjoy the benefits of *The Mechanical Universe* television series. The television programs are intended to supplement lectures and other forms of instruction traditionally used in this kind of course. There are a number of topics, treated as sections within chapters or as entire chapters, which are not covered at all in the television series. Moreover, the order in which subjects are presented in this book does not always correspond to the order of programs intended for broadcast television. The accompanying table indicates the correspondence between chapters and television programs (numbered in the order in which they are intended for broadcast).

Chapter	Program
1. Introduction	1. Introduction to *The Mechanical Universe*
2. The Law of Falling Bodies	2. The Law of Falling Bodies
3. The Language of Nature: Derivatives and Integrals	3. Derivatives 7. Integration
4. Inertia	4. Inertia
5. Vectors	5. Vectors 9. Moving in circles
6. Newton's Laws and Equilibrium	6. Newton's Laws Note: Sections 6.5 and 6.6, on static forces, are not treated in the television series.
7. Universal Gravitation and Circular Motion	8. The Apple and the Moon 9. Moving in Circles
8. Forces	10. Fundamental Forces 11. Gravity, Electricity, Magnetism 12. The Millikan Experiment
9. Forces in Accelerating Reference Frames	No television program for this chapter

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10. Energy: Conservation and Conversion	13. Conservation of Energy 14. Potential Energy
11. The Conservation of Momentum	15. Conservation of Momentum
12. Oscillatory Motion	16. Harmonic Motion 17. Resonance 18. Waves Note: Although waves are not specifically treated in this volume, Program 18 is largely a qualitative treatment of that subject.
13. Angular Momentum	19. Angular Momentum
14. Rotational Dynamics for Rigid Bodies	No television program for this chapter
15. Torques and Gyroscopes	20. Torques and Gyroscopes
16. Kepler's Laws and the Conic Sections	21. Kepler's Three Laws
17. Solving the Kepler Problem	22. The Kepler Problem 23. Energy and Eccentricity 25. From Kepler to Einstein
18. Navigating in Space	24. Navigating in Space
19. Temperature and the Gas Law	45. Temperature and the Gas Law
20. Engine of Nature	46. Engine of Nature
21. Entropy and the States of Matter	47. Entropy
22. The Quest for Low Temperature	48. Low Temperature

Note: Parts of Program 25 (From Kepler to Einstein) treat the tides and a brief mention of general relativity, topics not covered in this volume.

As one can see from the table, subjects such as noninertial frames (Chapter 9) and rotation of rigid bodies (Chapter 14) have been added to the material covered by the telecourse because they are considered appropriate to the preparation of science and engineering students. Many other subjects are covered more deeply, and most chapters include more challenging problems than would be presented to other students of *The Mechanical Universe*.

Science and engineering students who take a calculus-based physics course either have some knowledge of elementary calculus or take a separate calculus course concurrently with their physics course. The treatment of derivatives and integrals in Chapter 3 should be useful to both groups. It provides an early introduction of calculus topics that may be needed in physics before they are presented in a concurrent mathematics course,

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and for those who already know calculus it serves as a review. Care has been taken to make the material compatible with what the student might learn from a course taught by a professional mathematician.

Finally, the chapters on thermal physics, 19–22, have been placed at the end of the book to aid in flexibility of course design. For example, the first term of a three-quarter course might not include these chapters.

Throughout *The Mechanical Universe*, history is used as a means to humanize physics. It should go without saying that we don't expect students to memorize names and dates any more than we expect them to memorize detailed formulas and constants. *The Mechanical Universe* may or may not contribute to the vocational training of any given student. We hope it will contribute to their education.

IV ACKNOWLEDGMENTS

The Mechanical Universe textbooks, like the television series itself, would not have been possible without the cheerful and dedicated work of a long list of people who aided in its realization.

Special mention goes to *The Mechanical Universe* Local Advisory Committee, each member of which read and criticized in detail every chapter of the manuscripts, thus lending the benefit of their very considerable teaching experience: Keith Miller, Professor of Physics, Pasadena City College; Ronald F. Brown, Professor of Physics, California Polytechnic State University, San Luis Obispo; Eldred F. Tubbs, Member of the Technical Staff, Jet Propulsion Laboratory, Caltech; Elizabeth Hodes, Professor of Mathematics, Santa Barbara City College; and Eric J. Woodbury, Chief Scientist (retired), Hughes Aircraft Company.

In addition, parts of the manuscripts have been read and criticized by Margaret Osler (University of Calgary), Judith Goodstein (Caltech), and Robert Westman (UCLA), distinguished historians all; Dave Campbell (Saddleback Community College) and Jim Blinn (Jet Propulsion Laboratory), members of *The Mechanical Universe* team; Theodore Sarachman (Whittier College); and the entire 1983 and 1984 Caltech freshman classes.

In addition to all of these, homework problems were provided by Mark Muldoon and Brian Warr, and problems were checked for accuracy by Mark and Brian as well as by George Siopsis and Milan Mijic, all of Caltech.

Under the splendid direction of Project Secretary Renate Bigalke, the words and equations, mistakes and corrections of the authors were patiently and accurately rendered into the computer memory by Laurie Cornachio, Marcia Goodstein, and Sarb Nam Khalsa. All of the work was watched over anxiously by Hyman Field of the Annenberg/CPB Project (sponsors of *The Mechanical Universe*) and gently prodded along by David Tranah and Peter-John Leone of Cambridge University Press. We are especially pleased that Cambridge, which published Newton's *Principia*, has decided to follow it up with *The Mechanical Universe*. Sally Beaty, Executive Producer of *The Mechanical Universe* television series was present and instrumental at every important juncture in the creation of these books. Geraldine Grant and Richard Harsh supervised an extensive formal evaluation of various components of *The Mechanical Universe* project, including drafts of the chapters from this volume; the results of that effort have had their due effect on the final work. Carol Harrison sniffed out many photos and their sources for us.

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Finally, special thanks are due to Don Delson, Project Manager of *The Mechanical Universe*, who, through some miracle of organizational skill, cunning, and compulsive worrying, managed to keep the whole show going.

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