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PHYSICS IN OUR WORLD

PARTICLES AND THE UNIVERSE

KYLE KIRKLAND, PH.D.

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This book is printed on acid-free paper.

This book is dedicated to Professor George Gerstein, a remarkable scientist and an even more remarkable person.

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PREFACE

THE NUCLEAR BOMBS that ended World War II in 1945 were a convincing and frightening demonstration of the power of physics. A product of some of the best scientific minds in the world, the nuclear explosions devastated the Japanese cities of Hiroshima and Nagasaki, forcing Japan into an unconditional surrender. But even though the atomic bomb was the most dramatic example, physics and physicists made their presence felt throughout World War II. From dam-breaking bombs that skipped along the water to submerged mines that exploded when they magnetically sensed the presence of a ship's hull, the war was as much a scientific struggle as anything else.

World War II convinced everyone, including skeptical military leaders, that physics is an essential science. Yet the reach of this subject extends far beyond military applications. The principles of physics affect every part of the world and touch on all aspects of people's lives. Hurricanes, lightning, automobile engines, eyeglasses, skyscrapers, footballs, and even the way people walk and run must follow the dictates of scientific laws.

The relevance of physics in everyday life has often been overshadowed by topics such as nuclear weapons or the latest theories of how the universe began. Physics in Our World is a set of volumes that aims to explore the whole spectrum of applications, describing how physics influences technology and society, as well as helping people understand the nature and behavior of the universe and all its many interacting parts. The set covers the major branches of physics and includes the following titles:

- *Force and Motion*
- *Electricity and Magnetism*

- *Time and Thermodynamics*
- *Light and Optics*
- *Atoms and Materials*
- *Particles and the Universe*

Each volume explains the basic concepts of the subject and then discusses a variety of applications in which these concepts apply. Although physics is a mathematical subject, the focus of these books is on the ideas rather than the mathematics. Only simple equations are included. The reader does not need any special knowledge of mathematics, although an understanding of elementary algebra would be helpful in a few cases. The number of possible topics for each volume is practically limitless, but there is only room for a sample; regrettably, interesting applications had to be omitted. But each volume in the set explores a wide range of material, and all volumes contain a further reading and Web sites section that lists a selection of books and Web sites for continued exploration. This selection is also only a sample, offering suggestions of the many exploration opportunities available.

I was once at a conference in which a young student asked a group of professors whether he needed the latest edition of a physics textbook. One professor replied no, because the principles of physics "have not changed in years." This is true for the most part, but it is a testament to the power of physics. Another testament to physics is the astounding number of applications relying on these principles—and these applications continue to expand and change at an exceptionally rapid pace. Steam engines have yielded to the powerful internal combustion engines of race cars and fighter jets, and telephone wires are in the process of yielding to fiber optics, satellite communication, and cell phones. The goal of these books is to encourage the reader to see the relevance of physics in all directions and in every endeavor, at the present time as well as in the past and in the years to come.

Acknowledgments

THANKS GO TO my teachers, many of whom did their best to put up with me and my undisciplined ways. Special thanks go to Drs. George Gerstein, Larry Palmer, and Stanley Schmidt for helping me find my way when I got lost. I also much appreciate the contributions of Jodie Rhodes, who helped launch this project; executive editor Frank K. Darmstadt and the editorial and production teams who pushed it along; and the many scientists, educators, and writers who provided some of their time and insight. Thanks most of all go to Elizabeth Kirkland, a super mom with extraordinary powers and a gift for using them wisely.

INTRODUCTION

AS A STUDENT forced to flee Cambridge University during an epidemic in 1665–66, Isaac Newton—later knighted, becoming Sir Isaac—found a lot of time to do experiments. He put this time to good use, discovering the basis for many of the laws of physics he would go on to publish a few decades later. Newton's equations accurately described acceleration and motion, and his universal law of *gravitation* explained in a concise and mathematical way gravity on Earth as well as in the solar system.

The physics of Newton dominated physics for more than 200 years. In Newton's viewpoint, forces caused changes in motion, which could be precisely determined and calculated, and concepts such as space and time were absolute, the same for everyone. Physicists continued to accept this point of view until, in the 20th century, exceptions began to appear. With improved instruments and more imaginative theories, people began to probe objects and events that were not encountered in everyday life—tiny particles inside an *atom,* immense objects such as the entire universe, and small or large objects moving at exceptionally fast speeds. Laws described by Newton failed to hold true in many cases. New laws, and occasionally entirely new concepts, were needed. The new laws reduce to the old laws in familiar situations but increase their scope and accuracy.

Particles and the Universe documents the phenomena in which Newton's physics failed and explains "modern" physics that formed the basis for a new set of laws. One thing that did not change was the scientific method—observations lead to theories, which must be tested for accuracy. Each chapter of *Particles and the Universe* delves into the observations, theories, and tests of a particular topic:

- nuclear physics
- quantum mechanics
- particle physics
- relativity
- cosmology, the study of the universe

Nuclear physics investigates the properties and behavior of the central portion, or *nucleus,* of the atom. This branch of physics has had perhaps the biggest impact on the world in the 20th century because it evolved into knowledge that helped build the most destructive weapons people have ever known. The atomic bombs that ended World War II in 1945, and the weapons race that followed, changed the course of history. But applications of nuclear physics have also provided enormous *energy* for peaceful purposes, generating about 16 percent of the world's electricity.

The strange behavior of tiny particles such as the components of an atom required physicists to revise their theories, as well as the way that those theories are understood and applied. *Quantum mechanics* supplies the equations to describe the motion and properties of particles, but its measurements have peculiar features. Properties of objects tend to have a discrete nature—their values increase by specific amounts, like the integers (. . .–2, –1, 0, 1, 2,. . .) rather than being continuous, like the real number line, in which the value can be any number. Calculations in quantum mechanics also introduce an amount of uncertainty that can never disappear. Physicists dealt with uncertainty before quantum mechanics, but it was due to a lack of knowledge, not due to the nature of physics itself, as it is in the newer theory.

To probe the nature of matter even further, physicists have built gigantic accelerators capable of hurling particles down a pathway at nearly the speed of light. Crashes between high-speed particles have enough energy to tear them apart or to create entirely new particles, and hundreds of different particles exist. Particle physics is the branch of physics devoted to classifying these particles, identifying their properties, and explaining the forces they exert on each other as they interact.

Extremely fast speeds, such as those achieved by particle accelerators, were another phenomenon requiring a fresh perspective in physics. A few decades before huge accelerators were built, Albert Einstein, one of the greatest physicists of all time, concerned himself with the laws of physics as they would appear to observers in motion. Einstein believed physics should be the same for all observers, and his *special theory of relativity,* published in 1905, generated strange but accurate predictions of slowly moving clocks and shrinking lengths. The *general theory of relativity,* proposed a decade later, involved gravitation and had its own astonishing consequences, such as the discovery of objects in space so dense that not even light can escape them. Einstein's theories have survived every test so far.

The special and general theories of relativity are also important tools in the study of the universe. These theories help astronomers understand the observations made with telescopes and other instruments, which reveal a host of spectacular objects and events. One of the most fascinating phenomena is the expansion of the universe itself, a prediction of the general theory of relativity even Einstein refused to believe at first.

All chapters include a description of the profound changes caused by the new discoveries, along with applications such as earth-shattering weapons, machines to image the activity of a human brain, and precise satellite navigation systems. The rise of 20th-century physics altered the landscape of science, producing new ideas and theories that dramatically advanced scientific knowledge in previously unexplored realms of the universe.