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MODERN DEVICES

The Simple Physics of Sophisticated Technology

with website

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PREFACE

We all encounter sophisticated technology in many aspects of our daily lives. There are, of course, items that readily come to mind such as smart phones, tablets, personal computers, and the like. Technology, however, has also invaded every category of employment in the workplace. It is no longer unusual to see family farmers or construction workers using lasers to make precision measurements. Farmers in the not-too-distant future may commonly harvest crops at night as well as during the day. This flexibility will increase their efficiency. For instance, farmers would be able to share expensive field equipment with one farmer working in the night shift. Alternatively, they would have the option if necessary to conduct a burst of activities, performing critical farming operations in advance of say a pending change in weather. The night farming is made possible by the use of global positioning, which enables the farmer to maneuver his large equipment exactly (within inches) to plow or harvest during the darkest nights. He will also be able to apply minimal amounts of water, insecticides, and fertilizers only to those portions of his field requiring it based on satellite imaging.

In addition, many of us will be expected to become familiar with many more devices than we current are. Not only is there an ever-increasing array of new products to increase our productivity or to enhance our leisure, many of us will switch careers several times throughout our lives. Each time, we are likely to encounter a new, uniquely, and highly specialized set of tools and devices. Even those of us who stay with a single company are likely to encounter a diversity of technological gadgets. There has been, for example, a long tradition in the aerospace industry for senior engineers to evolve toward and eventually become managers where they then frequently find themselves making decisions about completely unfamiliar technologies. As more and more businesses incorporate technologically sophisticated instruments, the general work force will increasingly resemble aerospace companies in some respects. Their personnel will have to learn to deal effectively with new, unfamiliar technologies, repeatedly.

Moreover, many individuals will have to make decisions in response to new technological advances. Such individuals include financial investment advisors or economists, who will have to assess the potential payoff from costly and sometimes risky investments in emerging technologies. Government regulators will require a grasp of the benefits and downsides to new technological solutions to say, cleaning up the environment. Local government officials will have to assess the impact that the introduction of sophisticated technologies can have on a community. For that matter, political leaders will be making decisions on which high-tech systems should be deployed by the military as well as by other agencies. Many new systems will be expensive, and we as a society will have to weigh the effectiveness of these systems against the costs and then balance the new capability against other social needs. Even lawyers and judges will have to litigate more issues associated with technology, both from complainants with grievances as well as law suits over intellectual property rights.

A wide variety of individuals need to understand the basic concepts and the corresponding limitations behind various technologies. They need information that articulates the inherent strengths and limitations of these technologies, which can be obtained from an understanding of the physics of these modern devices. While technology is constantly evolving and improving, the basic underlying physics evolves very slowly, much longer than a human lifetime. There are relatively few physics principles, and fortunately each can be applied to numerous applications. This is the advantage of understanding the physics behind technologies. Rather than memorizing thousands of seemingly unrelated facts and data, one can learn a relatively few number of physical principles and then readily understand how many unfamiliar devices work. A better understanding of the physics will also aid in the interpretation of results, especially in identifying spurious or absurd measurements.

The current book is designed for professionals with a bachelors or higher degree who require a basic understanding of the operation of complex technologies. In the current "information glut" created by the Internet, there are numerous websites established to provide technical backgrounds on almost any subject. However, these web pages vary substantially from one site to another in the level of sophistication and the technical accuracy. Moreover, these sites often contain unclear or misleading physics. Some excellent websites at universities (e.g., at the University of Colorado and at Georgia State University) provide superb backgrounds over a wide range of physics topics but do not focus specifically on the common recurring physical principles behind sophisticated modern devices. This book fills this need at a consistent standard and is also suitable as textbook for an upper-level undergraduate college physics course for nonmajors. We describe the basic physics behind a large number of devices encountered in everyday life. There are many more topics than can realistically be taught in a two semester course. This encyclopedia style format is deliberate. Each device or topic is written essentially as a stand-alone article, allowing individuals or instructors to select the topics most suitable for their interests. Instructors at Rutgers University teach a non-majors course: The Physics of Modern Devices and have their students prepare 15-minute presentations on a topic of their choosing. The present text serves as a starting point for further exploration of other topics as well as serves as a useful reference book to professionals.

The approach is to present physics principles in an interesting context and in a non-threatening highly descriptive manner. It is thus an excellent resource for students who feel somewhat intimidated by physics and mathematics in general. It is assumed, however, that the student has taken an introductory physics course, college algebra, and had at least a minimal exposure to calculus.

This text contains many diagrams and sketches as well as graphs to help the student visualize the physics. There are also equations and mathematical analysis where appropriate. Both approaches enhance the reader's overall understanding and appreciation of the subject. The goal is to bring the reader quickly up to speed on the essential issues leading to the inherent strengths and limitations of various devices and associated technologies. Where possible, alternative technologies and any ongoing efforts to mitigate existing shortcomings are discussed. Each topic is intended to provide the reader with the insights necessary to ask intelligent questions on the relevant topics and to gain a greater appreciation of the basic physics principles that impact the operation of various modern equipment. It is hoped that the student gains an appreciation that no single device is optimal for all applications.

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ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com/go/joseph/moderndevices

The website includes:

- PowerPoint Slides

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PRINCIPLES OF PHYSICS AND THE RELEVANCE TO MODERN TECHNOLOGIES

The basic motivation that science, the scientific method, and scientific reasoning should be mastered by an increasingly large fraction of our population can be seen in Figure 1.1, which shows the volume of an individual's knowledge and understanding compared to the collective, comprehensive volume of all human experience. The gray areas represent the fragments grasped by an individual with some areas being connected (i.e., related) through various mental paths. Gray blobs that are clustered represent the formation of expertise in some field. Most of the volume (white area) is empty, indicating those topics where the individual is uninformed. As the figure depicts, the overall volume of knowledge and understanding is increasing rapidly with time. While the individual continues to grow and learn, adding more fragments as well as enhancing his/her expertise in some fields (larger, more concentrated gray area clusters), it is difficult to keep pace with all that one ought to understand. This task becomes virtually impossible if one relies solely on the incorporation of more factual knowledge, especially in a world that is increasingly becoming more reliant on technologies. A human being has a limited amount of memory that can be accessed with any reliability. The person who develops and incorporates scientific cognitive skills has a significant advantage since there are relatively few concepts underlying the physics behind all science and technology. Each fundamental theory can be applied to numerous applications, providing shortcuts to acquiring an understanding of new, unfamiliar equipment. The laws of physics are unchanging, and after basic concepts have been established, these evolve slowly on timescales of centuries. Basic scientific cognitive skills provide the individual with more mental tools, and he/she can exploit the observed commonalities between recognized and unfamiliar technologies.

All modern technologies are the exploitation of one or at most a few basic laws of physics. Insights into these governing principles illuminate simultaneously the intrinsic

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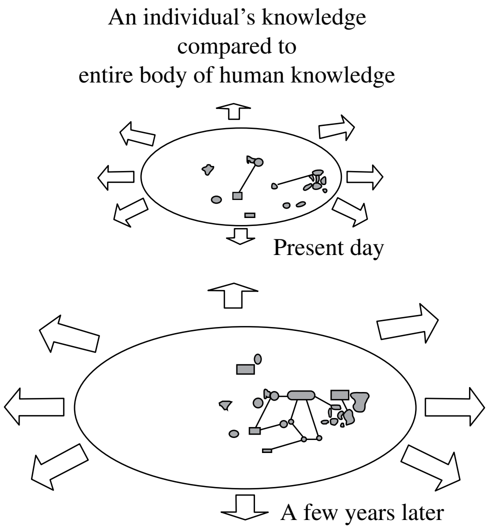

FIGURE 1.1 In the ever-expanding body of human knowledge, it is difficult for an individual to keep pace by only absorbing factual information. Gray areas represent small fragments of an individual's knowledge compared to all of the available data. Some of these fragments are connected (shown as lines) via various means (e.g., factual, cognitive, and reasoning).

operation as well as the inherent strengths and limitations of any apparatus or piece of equipment. Once optimized, there are only two ways to enhance the performance further. First, one performance parameter can often be enhance within limits at the expense of another. For example, power and speed in many electronics devices can be sacrificed against each other. Computing speed can be increased, but only at the expense of needing more power. Increased power consumption normally carries the penalties of greater cooling requirements, greater mass, and greater volume. Second, the only other way to enhance the performance of a device that has already been optimized is to switch to a totally different technology, one obeying a different set of physical laws.

The mastery of the underlying physics of modern equipment is satisfying, giving the student added insights into the equipment used throughout their careers. However, acquiring these cognitive skills does require some serious effort. It is important to bear in mind that in the early stages of learning physics, the individual has to absorb each rudimentary concept through the process of solving a number of similar problems. This learning process is similar in nature to a student learning a musical instrument, who must repetitively practice his or her scales and perform other repetitive exercises prior to the thrill and enjoyment of performing. The same is true of an individual taking up a new sport activity. He/she cannot expect to become a star without first receiving instruction on various techniques and plenty of practice. While rudimentary training cannot be avoided if the individual is to gain a solid understanding, the approach of the current text seeks to provide the motivational framework necessary to entice the student. The acquisition of new knowledge and new reasoning skills has to be a life-long endeavor, if one wants to rise above the crowd.