A SYSTEMS APPROACH

PHYSICS FOR TECHNICIANS

CENTER FOR OCCUPATIONAL
RESEARCH AND DEVELOPMENT

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Preface

In today's technologically oriented society, technicians play a role of ever-increasing importance. The services that they perform vary from the repair and maintenance of modern automobiles to the installation and adjustment of optical-fiber telecommunication networks. It is obvious that the education of technicians must include many hours of training in the tasks peculiar to the specific systems that they will service. In addition to this specific training, there are several general areas that make up the necessary background for the technician. For many, physics is a key element in that background.

In the traditional approach to technical physics, the usual subject matter is organized into separate sections on mechanics, electricity and magnetism, optics, thermodynamics, and so forth. In the presentation of individual topics, there is an emphasis on **derivations** *in the lecture class and* **proof of principles** *in the laboratory class. This traditional approach is quite proper for scientists and engineers, but fails to meet the needs of most technicians because several years of study are required to recognize the similarities between the basic quantities of physics in the various energy systems—mechanical, fluid, electromagnetic, and thermal—and to apply them effectively to the maintenance, modification, and repair of complex technical systems. A one-year course in traditional technical physics may not succeed in providing technicians with this important insight. Additionally, it may fail because the* *strong emphasis on derivations causes technicians to lose sight of the important physical principles and the* **application** *of these principles to real-world systems.*

The Unified Technical Concepts (UTC) approach attempts to meet the needs of technicians by unifying the basic physical concepts in four major systems—mechanical, fluid, electromagnetic, and thermal. In Unified Technical Concepts—Physics for Technicians, *developed for technician training in postsecondary schools, each of the concept modules, or chapters, begins with a development of the basic physics relevant to the physical concept in question. Then, the basic physical concept is identified as a unifying principle that is extended to a variety of problems in mechanical, fluid, electromagnetic, and thermal systems. For example, the concept module on force first covers the basic idea of a force, defining it as a push or pull, and applies it to linear and rotational mechanical systems. But, in addition, the idea of force as a unifying concept is introduced and extended to fluid, electromagnetic, and thermal systems. The concept module shows that a temperature difference, a pressure difference, and a voltage difference all behave like a force, even though these quantities are not forces and do not have the same dimensions as force (mass times length divided by time squared). In this manner, the concept of force is extended beyond the simple idea of a push or pull in mechanical systems and becomes a useful, unifying concept that aids the student in understanding motion in fluid, electromagnetic, and thermal systems. This general pattern of defining and explaining each concept and then demonstrating its application as a unifying concept in the four systems is continued throughout the text.*

The Unified Technical Concepts—Physics for Technicians *text—the forerunner to this text (*Physics for Technicians—A Systems Approach*)—includes thirteen concepts or chapters. These are:* **Force, Work, Rate, Momentum, Resistance, Power, Energy, Force Transformers, Energy Convertors, Transducers, Vibrations and Waves, Time Constants,** *and* **Radiation.** *Nine of these concepts are easily recognized as fundamental to physics, but four of the topics —***Force Transformers, Energy Convertors, Transducers,** *and* **Time Constants***—are generally not given extensive coverage in traditional technical physics texts even though they are important concepts for technician.*

One of the major strengths of the Unified Technical Concepts *text has been its emphasis on the laboratory experience. The laboratory exercises presented in the application modules enable the student to observe the physical principles that are presented in the concept modules. These application modules emphasize the hands-on learning experience that is more useful to the technician than the "blackboard approach" of most traditional physics courses. The concept and application modules of* Unified Technical Concepts *were developed as integrated components of a technical physics course and were not intended to stand alone, either as a text for a lecture course or as a laboratory manual.*

Unified Technical Concepts *has been used in postsecondary technical training programs since 1978 and has been well received. In addition, the UTC approach has been adopted as the framework for the development of a two-year high school course called Principles of Technology. Currently, some 43 states and provinces in North America are teaching Principles of Technology to high school vocational students who are interested in careers as technicians. Both of these training programs—Unified Technical Concepts Physics and Principles of Technology—have been successful in helping students learn technical physics.*

The development of Physics for Technicians—A Systems Approach—*has evolved from recommendations for changes in* Unified Technical Concepts. *The necessity for these changes has been driven by the increased level of preparation of students entering postsecondary schools and the increasing number of students who are completing Principles of Technology in the secondary schools. Based on recommendations from teachers who have been using* Unified Technical Concepts, *the* Physics for Technicians *text incorporates the following changes:*

- **The math content has been upgraded to a precalculus level.** *The development of the physical relationships employs notation and concepts that are common to calculus—such as the summation over a given element—without going into the calculus itself.*
- **The physics has been upgraded to include more equations and more derivations.** *Most of this material was previously found in the preparatory section of the application modules of* Unified Technical

Concepts. *Movement of this material into the text provides a better foundation for the lecture portion of the course and allows the labs that accompany* Physics for Technicians *to be "streamlined." This also makes* Physics for Technicians *more useful as a reference book for the working technician.*

- **Magnetism has been added to electricity and included in the discussion of the electromagnetic energy system throughout the text.**
- **A chapter on optics and lasers has been added to the thirteen chapters that formed the core of Unified Technical Concepts.**
- **Exercises for the students have been significantly increased in number and level at the end of each section.**

The revisions that are included in Physics for Technicians *do not reflect a change in philosophy. Rather, they build on the strengths of* Unified Technical Concepts. *Although* Physics for Technicians *can be used without the application modules, the laboratory exercises remain a very important part of the UTC program. It is strongly recommended that a minimum of sixty laboratory exercises be completed during the one-year course.*

It is hoped that the revisions made in Unified Technical Concepts*—those revisions that have led to* Physics for Technicians*—will meet the need for a practical course in technical physics. It is further hoped that* Physics for Technicians *will serve as a useful text and reference book for students and practicing technicians.*

Leno S. Pedrotti
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Acknowledgments

Extensive revisions and rewriting of Unified Technical Concepts—Physics for Technicians *led to this edition of* Physics for Technicians—A Systems Approach. *Significant recognition and credit are due Paul W. Schreiber, research physicist and teacher, for his arduous labors as principal author of the text. Recognition is also due Norman L. Baker, staff member, for his conscientious work as chief technical editor.*

L.S.P

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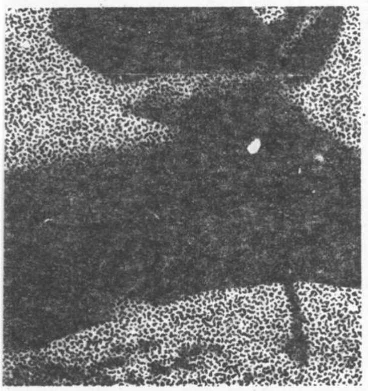
C H A P T E R 1

Force



INTRODUCTION

The concept of force is based on the common experiences of every person. A force is a push or pull that may cause an object to move. Force—a physical quantity that causes movement—is the "prime mover" in the mechanical energy system.

This chapter discusses the concept of force and forcelike quantities as they apply to four energy systems: ***mechanical, fluid, electromagnetic,*** *and* ***thermal.*** *The forcelike quantities discussed are force, torque, pressure difference, voltage difference, magnetomotive force, and temperature difference.*

- Force *causes motion of an object in a translational mechanical system. This force serves as the model for all forcelike quantities.*
- Torque *causes rotation of an object in a rotational mechanical system. Torque is a forcelike quantity.*
- Pressure difference *causes a fluid to move in a fluid system. Pressure difference is a forcelike quantity.*
- Voltage difference *causes charge to move in an electrical system. Voltage difference is a forcelike quantity.*

- Magnetomotive force *causes the existence of a magnetic field.*
  Magnetomotive force is a forcelike quantity.
- Temperature difference *causes heat energy to move in a thermal system.*
  Temperature difference is the forcelike quantity.

The discussion that follows includes the mathematical formulation and units used to describe each forcelike quantity in each energy system and stresses the characteristics of forcelike quantities that apply to all energy systems.

1.1 FORCE AND TORQUE IN MECHANICAL SYSTEMS

OBJECTIVES

Upon completion of this section, the student should be able to

- Define the physical quantities
  Force
  Torque
  and, where applicable, state their units in both SI units (international systems of units) and English Units.
- State Newton's second law of motion.
- Define
  Concurrent forces
  Coplanar forces
- Determine the resultant of concurrent forces.
- Use the conditions for the equilibrium of concurrent forces to find two unknowns.
- Given two of the following quantities in a mechanical rotational system, determine the third:
  Force
  Lever arm
  Torque
- Determine the resultant of a system of parallel forces.
- Use the conditions for the equilibrium of parallel forces to find two unknowns.
- Define
  Center of gravity
  Two-force member
  Multiply-force member
- Apply the conditions for equilibrium to coplanar, nonconcurrent forces and find three unknowns.