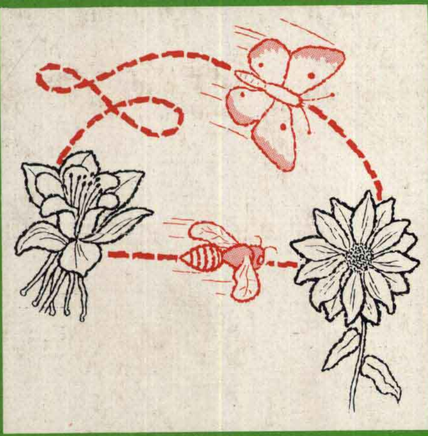

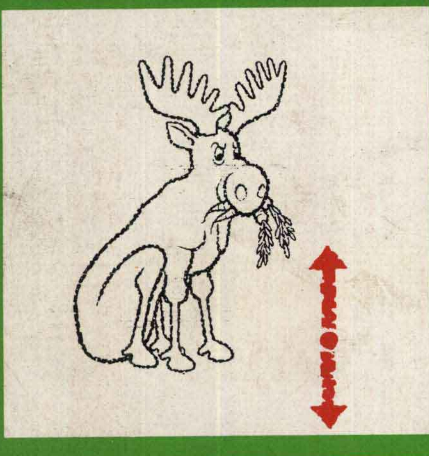

PHYSICS: Fundamentals & Frontiers

Ballif & Dibble

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Fundamentals & Frontiers

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Preface

In this book we present, in a nonmathematical way, the fundamental principles of physics. These are principles which have caused revolutionary changes in the way men think of the natural world which surrounds them. From a practical point of view, a knowledge of these principles is needed to understand the changing technology of modern civilization.

The book is designed for either a one-semester or a one-quarter course. All of the material can be covered in a one-semester course. In a shorter course it might be desirable to omit some topics.

We have profited from the responses of many of the thousands of students on whom this material has been tested. We are indebted to several of our colleagues, particularly B. Kent Harrison, for many helpful discussions. Suggestions from David Perry, Robert Smith, and Donald Wieber were very useful. We acknowledge the assistance and encouragement of the staff of John Wiley & Sons, particularly Donald H. Deneck, Gerhard R. Brahms, Bernard Scheier, Linda Riffle, Phyllis Niklas, Elodie Sabankaya, Stella Kupferberg, and John Balbalis.

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Contents

1 Introduction

Science is the creation of concepts and their exploration in the facts. It has no other test of the concept than its empirical truth to fact. Truth is the drive at the center of science; it must have the habit of truth, not as a dogma but as a process.

J. Bronowski[1]

Throughout history, men and women have tried to understand their environment—an environment into which birth so suddenly and so strangely places them. Sometimes necessity forces this attempt at understanding. Food, shelter, protection from enemies, all must be wrested from an often stubborn and unforgiving earth. Sometimes, however, it appears to be a natural and driving curiosity that prompts a person to seek for the fundamental principles, forces, and elements that form, structure, and order the changing appearances and perplexing variety of nature.

Science and Technology

When we try to apply scientific information to achieve a specific purpose, to obtain food, shelter, protection, or some

[1]Reprinted from SCIENCE AND HUMAN VALUES by J. Bronowski by permission of Julian Messner, A Division of Simon & Schuster, Inc. Copyright © 1956, 1965 by J. Bronowski.

FIGURE 1-1 Courtesy of Syd Greenberg, DPI.

other desired product or result, we are engaging in technology. All of us have some interest in technology, if for no other reason than that we need food to eat, water to drink, and air to breathe. Logically speaking, however, before we can have any technology, our present technology or any other that we decide upon, we must have information to apply. This is one place where science comes into the picture. The activities of science are the search for reliable information and its organization into fundamental laws and principles. On the basis of these laws and principles one can then predict how nature will behave in a wide variety of circumstances. Thus one can create technologies. But science is not technology, rather it is more aptly described, as J. Bronowski has put it, as "the search to discover unity in the wild vaariety of nature—or more exactly, in the variety of our experience."[2] In this book we shall consider many of the fundamental laws which help to bring such unity to our understanding of nature.

Physics is generally considered to be the most fundamental of the sciences, providing much, if not all, of the scientific basis for chemistry, geology, and the various fields of engineering. Physics may be said to be the study of space, time, and matter—a rather all inclusive subject.

Indeed, physics *is* concerned with the elementary particles and fields of matter and energy, their behavior under various forces, and the structure, properties, and behavior of the larger aggregates of matter composed of many particles. Today even systems as complicated as living cells and the nervous systems of animals can be profitably studied by the methods of physics.

In the course of our discussion of the principles and development of physics, we shall have occasion to discuss and comment on the methods of science, and the way in which scientific principles are verified. At the outset, however, we should realize that although correct and clear reasoning is very important in physics, physics is an *experimental* science. This means that its principles and laws should be tested by experiment, and that if they fail to hold they should be rejected or modified. In general, a theory may be proposed to explain a number of facts. Predictions are then made on the basis of the theory, and experiments are performed to see if the predictions of the theory actually hold true. If they do, then the theory will be gener-

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ally accepted. As we shall see by specific examples later, however, it may happen that a theory passes many tests, becomes widely and solidly accepted, and then finally fails to meet the test of some new experiment. Thus the theory is never absolutely proved, because new evidence may disprove it. Several times in the development of physics, new evidence has required revolutionary changes, changes which seemed and still seem to require new attitudes toward nature and even toward truth itself. One of the particular purposes of this book is to discuss two such revolutions.

Two Scientific Revolutions

The first revolution is associated with the names (among others) of the Italian Galileo Galilei (1564–1642), his German contemporary Johannes Kepler (1571–1630), and the man who tied it all together, the Englishman Isaac Newton (1642–1727). The revolutionary idea that the earth moved caused major revisions in physics, astronomy, philosophy, and theology. Those holding to traditional views became offended and even enraged over the new philosophy. In the ensuing battle, the scientific revolution gained its heroes, its villains, and its martyrs. The new ideas have shaped our present view of the cosmos, and the new methods of thought have shaped much of what is thought of as "scientific" even today. The cosmos was, as it were, cut from its moorings, and a whole world view was changed.

The impact of the second revolution, it appears to us, is less widely appreciated than that of the first. Neither Albert Einstein (1879–1955), Max Planck (1858–1947), Niels Bohr (1885–1962), Louis de Broglie (1892–), Erwin Schrodinger (1887–1961), Werner Heisenberg (1901–), nor Paul Dirac (1902–) were burned at the stake or imprisoned as far as we know (though some people might not have objected). Yet, the principles of relativity and quantum physics appear to be as challenging to traditional ideas of nature and truth as were the ideas of the first scientific revolution.

At the risk of oversimplification, we should like also to contrast two technologies. (See Figures 1-2 and 1-3). The technology of the last two hundred years or so created mechanical devices, and eventually electrical and electromechanical devices. It exploited "conventional" energy sources in coal, petroleum, and water power. With these devices and energy sources it established rapid transportation over land, water, and through the air; indeed through space itself. With these devices and energy sources it increased production of

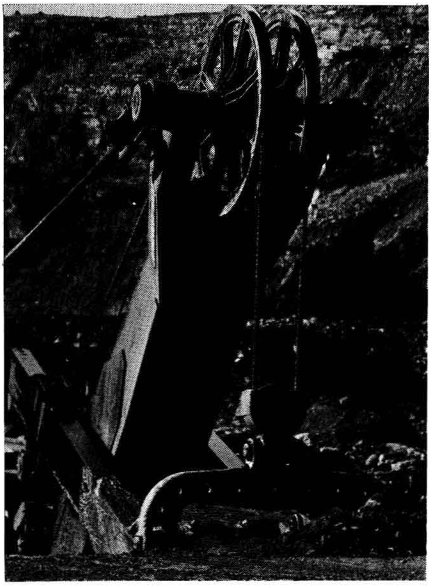

FIGURE 1-2 **Discoveries of the first scientific revolution have long had their application in the design of heavy equipment. Courtesy of David Crofoot, DPI.**

food, manufactures, and more machines to add to the "muscle power" of the human race.

The new physics, of the second revolution, has already its technological applications as well. Many of these applications arise from facts and principles discovered from the study of the invisible—particles and systems much too small to be seen even in a light microscope. Nuclear processes offer a vast new source of energy, when properly harnessed. The electron microscope and the laser operate on "quantum" principles. The transistor and related devices have made electronic circuits much more compact. The computer, which only a few years ago took up an entire room, can now be made as small as a suitcase. A true technological revolution, the information revolution, appears to be well started. Computers and other information processing equipment are taking over more and more of the mental drudgery of the human race. Information processing, statistical prediction and decision making, and automatic control may be as characteristic of our time as steel production and railways were of another.

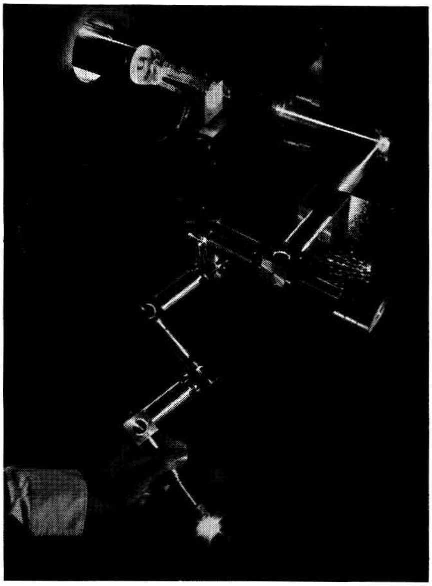

FIGURE 1-3 **An example of modern technology: Laser "knife" developed at Bell Laboratories has an articulated arm that allows the beam from a stationary laser to be moved freely for use in surgery, microcircuit fabrication or many other applications. Courtesy of William Vandivert.**

Again, however, we must emphasize that technology is not science, although science opens new possibilities for technology. A scientist may tell us that a nuclear energy project is possible, an engineer may tell us what it will cost, and together they can perhaps tell us what side effects it will have and how safe it will be. Neither of them can tell us whether we want the new project or not, nor would we want them making that decision for us. That is the responsibility of the citizen, not of any special class or expertise. Nor is it necessary to be able to build or operate a nuclear power plant yourself in order to make a reasonably intelligent decision. It would be useful, however, to know what energy is, and what a nucleus is.

Increasingly, political decisions are going to require scientific evaluations. We hope that the subjects we will discuss will be of some help in building a general understanding of physical principles that may be of use in such decisions. Of course, we are also interested in the subject for its own sake, and hope to appeal to your natural curiosity as well.

Quantities

Many of the laws of physics are expressed in terms of physical quantities, such as distance and time duration. We shall begin the discussion of the laws of physics in the next chapter. Here, however, we would like to discuss some of the quantities with which we shall be concerned.

Quantities and Measurement

A *quantity* may be defined, roughly, as an observable property or process in nature with which a number may be associated. This number is obtained by the operation of *measurement*. The number may be obtained directly by a single measurement, or indirectly, as, for example, by multiplying together two numbers obtained in separate operations of measurement. In this section we will first be concerned with the quantities *distance* and *time duration*. We obtain distances by making measurements of space. We obtain time durations by making measurements of time. Almost everyone has had practical experience making measurements of distance using rulers and making measurements of time duration using clocks. Of course measurements of these quantities are made only to a certain degree of accuracy. Greater accuracy generally requires greater care or more elaborate equipment.

Fundamental quantities are those which we choose *not* to define in terms of other quantities. For example, we choose distance and time duration to be fundamental; space and time seem very basic to us. Other quantities, which we can then define in terms of the fundamental quantities, are called *derived* quantities.

Scalar quantities can be specified using a single number. For example, the length of a rope is a scalar quantity. Some quantities cannot be specified completely without a direction as well as a number. For example, we cannot completely describe the motion of an object without giving the direction of its motion. A quantity that has a direction as well as a number is called a *vector* quantity. We must distinguish between scalar and vector quantities because they obey different rules of arithmetic, as we shall see in Chapter 4 where vector quantities are more precisely defined.

The Unit and Standard of Distance

We measure a distance in terms of some other distance. We say, for example, that the distance from Chicago to New York is 713 miles. The number 713 alone is not enough; we need the whole term, 713 *miles*, in order to indicate the distance correctly. The *mile*, which is itself a distance, is the unit in terms of which we usually measure the distance from Chicago to New York. We may thus define a *unit* of distance as that distance in terms of which we measure other distances. We could, of course, choose any distance we liked for our unit: a mile, a foot, an inch. In fact, we shall choose a unit commonly used in scientific work—the *meter.*

In order to define the meter (or any unit of distance), we need to have some sample distance we can rely on. We need some material object that will give us a distance to which we can refer. This material object, properly used, is the *standard* of distance. For a long time the standard of distance was a rigid bar, made of a corrosion-resistant metal alloy, which was kept in a controlled environment at a constant temperature and pressure (see Fig. 1-4). This bar had a thin scratch near each end. The distance between those scratches was defined to be one meter. Rulers one meter long were constructed by comparing them with the bar, and other distances were measured in meters using these rulers. A meter is exactly equal to 39.37 inches.

The rigid metal bar has been supplanted by another standard of distance.[3] However, it illustrates the use of standards and units in physics: quantities are measured in terms of units. These units can be defined by using suitable material objects or processes as standards.

The Unit and Standard of Time Duration

For our unit of time duration we shall choose the familiar *second.* There is, of course, no direct way to compare a second of time that

[3]In this book we shall use standards which are accessible and convenient for the purpose at hand. Sometimes, therefore, we shall not use the most precise standard currently adopted by scientists. We note here, for completeness, without describing the matter in detail, that currently the meter is defined in terms of the wavelength associated with a certain spectral line. The second is defined in terms of a particular atomic clock.

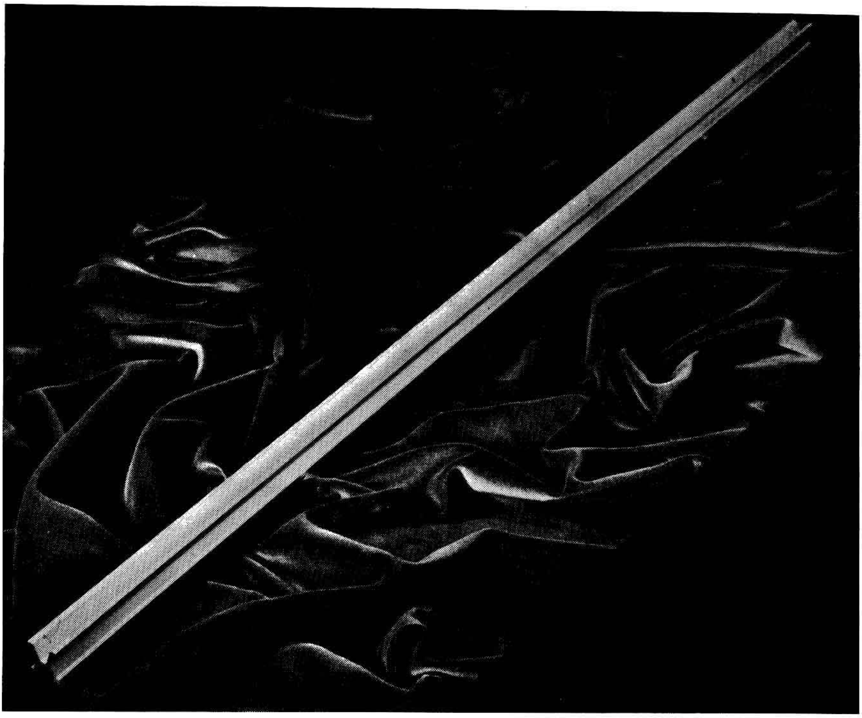

FIGURE 1-4 **Meter No. 27 at the National Bureau of Standards. This bar is similar to the original standard bar in Paris. Courtesy of the National Bureau of Standards.**

elapsed twenty years ago with a second of time today. Thus there is a problem in deciding just what should be called a second of time. The solution is to consider some process which happens over and over again in essentially the same way, such as the swinging of a pendulum or the rotation of the earth. We then agree that each seemingly identical process takes the same time. For our purposes here, we may consider that the earth takes the same time for each rotation (which is very nearly true) and obtain the *second* as our unit of time duration as follows: the second is defined as one 86,400th part of the earth's daily rotation period. In other words, there are 86,400 seconds in a day. (There are 60 seconds in a minute, 60 minutes in an hour, and 24 hours in a day. $60 \times 60 \times 24 = 86,400$.)

Derived Quantities

In our considerations of matter in motion, we will need to define many other quantities. However, we do not consider most of these quantities fundamental since they can be derived from other quantities. Area, speed, and velocity are examples of such *derived quantities*.

Area. If we have a rectangular region six meters long and three meters wide, we obtain the area of the region by multiplying these two distances together:

$$6 \text{ meter} \times 3 \text{ meter} = 18 \times (\text{meter}) \times (\text{meter}) = 8 \text{ meter}^2$$
$$= 18 \text{ square meters}$$

Note that we can multiply units together just as if they were numbers. We multiply meter times meter and get meter squared, or, as we call it, "square meters." The unit of area is the square meter, or meter^2.

Just as we obtained an area by multiplying two distances together, so we can obtain a volume by multiplying three distances together. To find the volume of a rectangular object—for example, a brick—we multiply together its length, width, and height. The unit of volume is the cubic meter, or meter^3.

Speed and Velocity. A useful quantity associated with the motion of an object is its *speed*. The speed is determined by the amount of distance traveled by the object in a given time duration. In order to derive the quantity speed, we divide the fundamental quantity distance by the fundamental quantity time duration. For example, suppose that an object travels 10 meters in two seconds. We divide 10 meters by two seconds and obtain a speed of five meters per second:

$$\frac{10 \text{ meter}}{2 \text{ second}} = 5 \frac{\text{meter}}{\text{second}} = 5 \text{ meters per second}$$

(In this example, we are assuming that the speed does not change in these two seconds.) Thus, in general we obtain the speed of a moving object by dividing the distance traveled by the time duration. The unit of speed is

$$\text{meter per second} = \frac{\text{meter}}{\text{second}}$$

This unit is obtained by dividing the unit of distance by the unit of time duration.

Speed alone does not completely describe the motion of an object. We also need to know the direction in which the object is moving. Therefore, it is convenient to define a new quantity, which includes both the speed and the direction of a moving object. This quantity is called *velocity*. In order to specify the velocity of an object, we must give both the speed of the object and the direction in which it is traveling. Because it includes the direction, velocity is a vector quantity. Speed, on the other hand, is a scalar quantity and it omits the direction.

FUNDAMENTAL IDEAS

I. GENERAL INTRODUCTION TO SCIENCE

- **A.** SCIENCE AND TECHNOLOGY AND THE DISTINCTION BETWEEN THEM
- **B.** TWO SCIENTIFIC REVOLUTIONS

II. QUANTITIES. These are obtained by measurement or by combining other quantities that are obtained by measurement.

- **A.** FUNDAMENTAL QUANTITIES
  1. Distance, a scalar.
  2. Time duration, a scalar.
- **B.** DERIVED QUANTITIES
  1. Area, a scalar.
  2. Volume, a scalar.
  3. Speed, a scalar.
  4. Velocity, a vector.

QUESTIONS

General Introduction to Science

1. Explain what is generally meant by science, physics, and technology.
2. Which of the following activities are more nearly science and which are more nearly technology: repairing a television set, designing a television set, searching for the cause of cancer, searching for a cure for can-