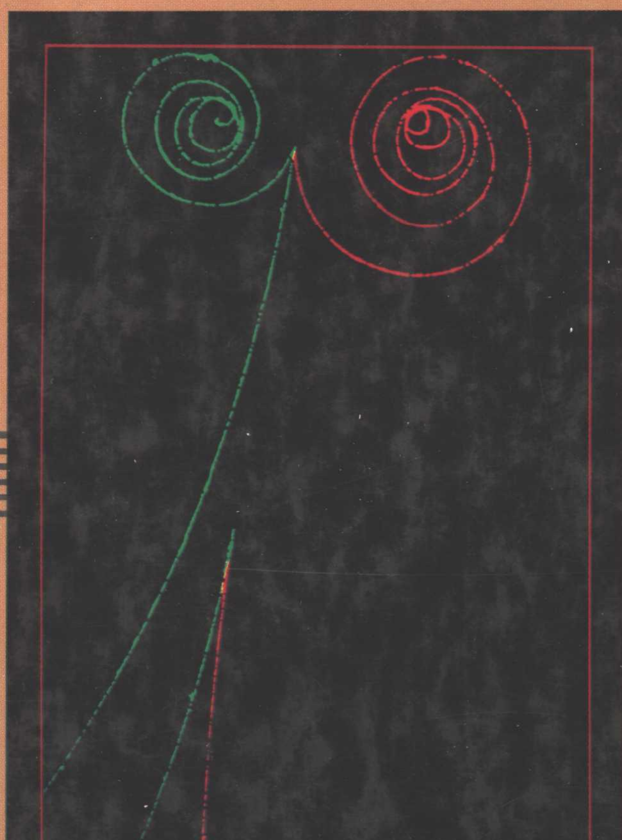
VOLUME I

Douglas C. Giancoli

PHYSICS FOR SCIENTISTS AND ENGINEERS

WITH MODERN PHYSICS



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PHYSICS

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Douglas C. Giancoli

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CHAPTER

1
INTRODUCTION

Although the earliest scientific ideas date back to early recorded history, physics as we know it today began with Galileo Galilei (1564–1642). Galileo and his successor Isaac Newton (1642–1727) created a revolution in scientific thought. The physics that developed over the next three centuries, reaching its culmination with the electromagnetic theory of light in the latter half of the nineteenth century, is now referred to as *classical physics.* By the turn of the last century, it seemed that the physical world was very well understood. But in the early years of the twentieth century, new ideas and new experiments in physics indicated that some aspects of classical physics did not work for the tiny world of the atom or for objects traveling at very high speed. This brought on a second great revolution in physics, which gave birth to what is now called *modern physics.*

1–1 Science and Creativity

The principal aim of all sciences, including physics, is generally considered to be the ordering of the complex appearances detected by our senses—that is, an ordering of what we often refer to as the "world around us." Many people think of science as a mechanical process of collecting facts and devising theories. This is not the case. [redacted]

Let's take some examples to see why this is true. One important aspect of science is *observation* of events. But observation requires imagination, for scientists can never include everything in a description of what they observe. Hence, scientists must make judgments about what is relevant in their observations. As an example, let us consider how two great minds, Aristotle (384–322 B.C.) and Galileo, interpreted motion along a horizontal surface. Aristotle noted that objects given an initial push along the ground (or on a tabletop) always slow down and stop. Consequently, Aristotle believed that the natural state of a body is at rest. Galileo, in his reexamination of horizontal motion in the early 1600s, chose rather to study the idealized case of motion free from resistance. In fact, Galileo imagined that if friction could be eliminated, an object given an initial push along a horizontal surface would continue to move indefinitely without stopping. He concluded that for an object to be in motion was just as natural as to be at rest. By seeing something new in the same "facts," Galileo is often given credit for founding our modern view of motion (more details in Chapter 2).

Theories are never derived from observations—they are *created* to explain observations. They are inspirations that come from the minds of human beings. For example, the idea that matter is made up of atoms (the atomic theory) was certainly not arrived at because someone observed atoms. Rather, the idea sprang from a creative mind. The theory of relativity, the electromagnetic theory of light, and Newton's law of universal gravitation were likewise the result of inspiration.

As creative achievements, the great theories of science may be compared with great works of art or literature. But how does science differ from these other creative activities? One important difference is that science requires *testing* of its ideas or theories to see if predictions are borne out by experiment. Indeed, careful experimentation is a crucial part of physics.

Although the testing of theories can be considered to distinguish science from other creative fields, it should not be assumed that a theory is "proved" by testing. First of all, no measuring instrument is perfect, so precise confirmation cannot be possible. Furthermore, it is not possible to test a theory in every single possible circumstance. Hence a theory can never be absolutely verified.† In fact, theories themselves are generally not perfect—a theory rarely agrees exactly, within experimental error, in every single case in which it is tested. Indeed, the history of science tells us that theories come and go; that long-held theories are replaced by new ones. The process of one theory replacing another is an important subject in the philosophy of science today; we can discuss it here only briefly.

A new theory is accepted by scientists in some cases because its predictions are quantitatively in much better agreement with experiment than is the older theory. But in many cases, a new theory is accepted only if it explains a greater *range* of phenomena than does the older one. Copernicus's sun-centered theory of the universe, for example, was no more accurate than Ptolemy's earth-centered theory for predicting the motion of heavenly bodies. But Copernicus's theory had consequences that Ptolemy's did not: for example, it made possible a determination of the order and distance of the planets and predicted the moonlike phases in the appearances of Venus. A simpler (or no more complex) and richer theory, one which unifies and explains a greater variety of phenomena, is more useful and beautiful to a scientist. And this aspect, as well as quantitative agreement, plays a major role in the acceptance of a theory.

An important aspect of any theory is how well it can quantitatively predict phenomena; and from this point of view, a new theory may often seem to be only a minor advance over the old one. For example, Einstein's theory of relativity gives predictions that differ very little from the older theories of Galileo and Newton in nearly all everyday situations; its predictions are better mainly in the extreme case of very high speeds close to the speed of light. From this point of view, the theory of relativity might be considered as mere "fine-tuning" of the older theory. But quantitative prediction is not the only important outcome of a theory. Our view of the world is affected as well. As a result of Einstein's theory of relativity, for example, our concepts of space and time have been completely changed; and we have come to see mass and energy as a single entity (via the famous equation $E = mc^2$). Indeed, our view of the world underwent a major change when relativity theory came to be accepted.

1–2 Models, Theories, and Laws

When scientists are trying to understand a particular set of phenomena, they often make use of a **model**. A model, in the scientists' sense, is a kind of analogy or mental

† Some philosophers therefore emphasize that testing of a theory can be used only to *falsify* it, not to confirm it—and/or to put a limit on its range of validity.