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Some Preliminaries

Albert Einstein (1879, Austria–1955). Giant of 20th-century physics. Doctorate, Polytechnic Academy, Zurich, 1905; also year of four epochal papers—special theory of relativity, equivalence of mass and energy, theory of Brownian motion, photon theory of light. 1916, general theory of relativity. 1921, Nobel Prize, photoelectric effect. 1933, joined Institute for Advanced Studies, Princeton, which was founded for Einstein. 1939, wrote to President Franklin D. Roosevelt urging the development of nuclear energy from uranium. (Photo courtesy of American Institute of Physics, Niels Bohr Library.)

What is modern physics? How does it differ from classical physics, and how is it similar? Which central ideas of classical physics can be carried over unchanged into modern physics, and which must be modified or replaced? These questions and other important ones are dealt with in this introductory chapter.

1-1 The Program of Physics

The program of physics is to devise concepts and laws that can help us to understand the universe. Physical laws are constructions of the human mind, subject to all the limitations of human understanding. They are not necessarily immune to change, and nature is not compelled to obey them.

A law in physics is a statement, usually in the succinct and precise language of mathematics, of a relation that has been found by repeated experiment to hold among physical quantities and that reflects persistent regularities in the behavior of the physical world. A "good" physical law has the greatest possible generality, simplicity, and precision. The final criterion of a successful law of physics is how accurately it predicts experimental results. On the other hand, extrapolating any law beyond its range of tested validity may predict results inconsistent with later experiments. One famous example of this was the Michelson-Morley experiment (see Chapter 2), which refuted the 19th-century conception of the ether as the medium for the propagation of electromagnetic waves. Such contradictions of theory are an important part of the evolution of physics. Early theories and laws that prove inadequate are supplanted by more general, comprehensive theories and laws that describe phenomena in the new, as well as the old, regions of investigation. Figure 1–1 shows the regions in which *classical physics, relativity physics, quantum physics*, and *relativistic quantum physics* apply.

Classical physics is the physics of ordinary-sized objects moving at ordinary speeds; it embraces Newtonian mechanics and electromagnetism. For speeds approaching the speed of light, classical physics must be supplanted by relativity physics; for sizes of about 10^{-10} m (approximately

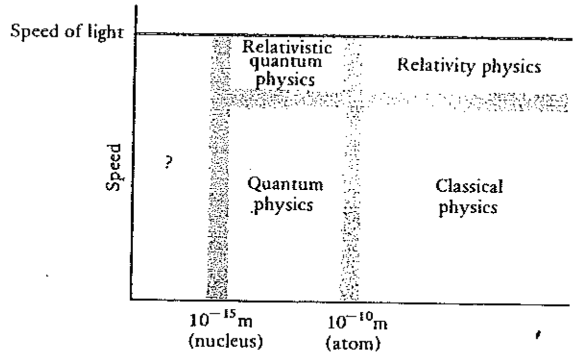

FIGURE 1–1. *Regions of applicability of various physical theories.*

the size of an atom), classical physics must be supplanted by quantum physics. For subatomic dimensions and speeds approaching the speed of light, only relativistic quantum physics is adequate. The limits of the several physical theories are not sharply defined; in fact, they overlap. Relativistic quantum physics is the most comprehensive and complete theoretical structure in present-day physics. At dimensions of about 10^{-15} m (the approximate size of the atomic nucleus) perplexing phenomena appear, at present only partly understood. Similarly, important cosmological questions remain unresolved in the domain of the very large (of the order of 10^{25} m).

Our understanding of atomic and nuclear structure is grounded in the two great ideas of modern physics, relativity theory and quantum theory. Both originated early in this century, when improved experimental techniques first allowed physicists to study phenomena at small enough dimensions and high enough speeds and energies. Indeed, by *modern* physics we mean the physics of the twentieth century.

After reviewing some crucial aspects of classical physics, we shall study relativity theory and quantum theory and use them to analyze atomic and nuclear structure. We shall deal with situations in which some familiar notions in physics may be inapplicable—situations in which classical physics is downright wrong. Does this mean, then, that all the time and effort spent in studying elementary classical physics is wasted, that one might better begin with relativity and quantum theory? Not at all! All results of experiment, however remote from our ordinary experience, must ultimately be expressed in classical terms—that is, in the classical concepts of momentum, energy, position, and time. Furthermore, we shall see that many of the concepts and laws of classical physics carry over into the new physics.

1-2 The Correspondence Principle

As we mentioned before, any theory or law in physics is more or less tentative and approximate; extrapolation to untested situations may show that it is incomplete or incorrect. If a new, more general theory is proposed, there is a completely reliable guide for relating the new theory to the older, more restricted one. This guide, the *correspondence principle,* was first proposed by the Danish physicist Niels Bohr in 1923 and applied to the theory of atomic structure. We shall find it helpful to apply this principle in a broader sense to both relativity physics and quantum physics.

> *The Correspondence Principle: Any new theory in physics, whatever its character or details, must reduce to the well-established classical theory to which it corresponds when it is applied under the circumstances in which the less general theory is known to hold.*

For example, when we are analyzing the motion of a projectile with a comparatively small range, we make the following assumptions: (1) The weight of the projectile is constant in magnitude and is given by the mass times a gravitational acceleration that is constant in magnitude; (2) the earth is represented by a plane surface, and (3) the weight of the projectile is constant in direction, vertically downward. With these assumptions, the theory predicts a parabolic path—in excellent agreement with experiment, provided that the projectile motion extends over only relatively short distances. However, if we try to describe the motion of an earth satellite on the same assumptions, *very* serious errors will be made. To discuss the satellite motion we must instead assume that (1) the weight of the body is *not* constant in magnitude but varies inversely with the square of its distance from the earth's center; (2) the earth's surface is spherical, not flat; and (3) the direction of the weight is *not* constant but always points toward the earth's center. With these assumptions, the theory predicts an elliptical path and describes satellite motion properly. Now, if we apply the second, more general, theory to the motion of a body traveling a distance that is small compared with the earth's radius at the surface of the earth, notice what happens. The weight appears to be constant in both magnitude and direction, the earth appears flat, and the elliptical path becomes parabolic. This is precisely what the correspondence principle requires!

The correspondence principle asserts that when the conditions of the new and old theories correspond, the predictions will also correspond; that is, a new (general) theory will yield the old (restricted) theory as a special approximation. We have, then, an infallible guide when testing a new theory or law: The new theory must reduce to the theory it supplants. Any new theory that fails in this respect is so fundamentally defective that it cannot possibly be accepted. Therefore, we know that the relativity and quantum theories *must* yield classical physics when applied to large-scale objects moving at speeds much lower than the speed of light. In the next section, we shall see another familiar example of the correspondence principle.