Chapter 1 The History and Limitations of Classical Mechanics

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Chapter 1.1 Introduction

Classical mechanics is the mathematical science that studies the displacement of bodies under the action of forces. Gailieo Galilee initiated the modern era of mechanics by using mathematics to describe the motion of bodies. His *Mechanics,* published in 1623, introduced the concepts of force and described the constant accelerated motion of objects near the surface of the Earth. Sixty years later Isaac Newton formulated his Laws of Motion, which he published in 1687 under the title, *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*). In the third book, subtitled *De mundi systemate* (*On the system of the world*), Newton solved the greatest scientific problem of his time by applying his Universal Law of Gravitation to determine the motion of planets. Newton established a mathematical approach to the analysis of physical phenomena in which he stated that it was unnecessary to introduce final causes (hypothesis) that have no experimental basis, *"Hypotheses non fingo* (I frame no hypotheses), but that physical models are built from experimental observations and then made general by induction. This led to a great century of applications of the principles of *Newtonian mechanics* to many new problems culminating in the work of Leonhard Euler. Euler began a systematic study of the three dimensional motion of rigid bodies, leading to a set of dynamical equations now known as *Euler's equations of motion*.

Alongside this development and refinement of the concept of force and its application to the description of motion, the concept of energy slowly emerged, culminating in the middle of the nineteenth century in the discovery of the *principle of conservation of energy* and its immediate applications to the laws of *thermodynamics*. Conservation principles are now central to our study of mechanics; the conservation of momentum, energy, and angular momentum enabled a new reformulation of classical mechanics.

During this period, the experimental methodology and mathematical tools of Newtonian mechanics were applied to other non-rigid systems of particles leading to the development of *continuum mechanics*. The theories of *fluid mechanics*, *wave mechanics*, and *electromagnetism* emerged leading to the development of the wave theory of light. However there were many perplexing aspects of the wave theory of light, for example, does light propagate through a medium, the "ether"? A series of optics experiments, culminating in the Michelson-Morley experiment in 1887 ruled out the hypothesis of a stationary medium. Many attempts were made to reconcile the experimental evidence with classical mechanics but the challenges were more fundamental. The basics concepts of absolute time and absolute space, which Newton had defined in the *Principia,* were themselves inadequate to explain a host of experimental observations. Albert Einstein, by insisting on a fundamental rethinking of the concepts of space and time, and the relativity of motion, in his *special theory of relativity* (1905) was able to resolve the apparent conflicts between optics and Newtonian mechanics. In particular, special relativity provides the necessary framework for describing the motion of rapidly moving objects (speed greater than $v > 0.1c$).

A second limitation on the validity of Newtonian mechanics appeared at the microscopic length scale. A new theory, *statistical mechanics*, was developed relating the microscopic properties of individual atoms and molecules to the macroscopic or bulk thermodynamic properties of materials. Started in the middle of the nineteenth century, new observations at very small scales revealed anomalies in the predicted behavior of gases (heat capacity). It became increasingly clear that classical mechanics did not adequately explain a wide range of newly discovered phenomena at the atomic and sub-atomic length scales. An essential realization was that the language of classical mechanics was not even adequate to qualitatively describe certain microscopic phenomena. By the early part of the twentieth century, *quantum mechanics* provided a mathematical description of microscopic phenomena in complete agreement with our empirical knowledge of all non-relativistic phenomena.

In the twentieth century, as experimental observations led to a more detailed knowledge of the large-scale properties of the universe, Newton's Universal Law of Gravitation no longer accurately modeled the observed universe and needed to be replaced by *general relativity*. By the end of the twentieth century and beginning of the twenty-first century, many new observations, for example the accelerated expansion of the Universe, have required introduction of new concepts like *dark energy* that may lead once again to a fundamental rethinking of the basic concepts of physics in order to explain observed phenomena.

8.01 Classical Mechanics

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