1.7 Classical physics

Classical physics is based on three things. The first basis is that the phenomena that are studied are those that we can directly observe, or that we can describe using theories based on such things. The second basis is the assumption that time and distances are fixed. When we measure the passage of time, that measurement will be the same no matter where we make it. The same for distance, if we measure the length of a table top and measure the same table top somewhere else, the measurement will be the same. The third thing is that given complete information about the current properties of a phenomena, we can accurately predict its future and past properties; such a system is called *deterministic*.

In a very real sense we are all classical physicists—it is hard-wired into our brains. Every day we do things involving complicated calculations that we take for granted. We wad up paper and throw it into a trash can. We do this without explicitly considering trigonometry-based vector differential equation calculations of trajectories, gravitation, and air-resistance. It is built-in. As we get more advanced, even in classical physics, some ideas come out that require us to re-wire our brains.

In fact, we can state that the purpose of physics education is to promote this necessary rewiring to occur. How do you learn physics? Learn the facts as you learn the techniques to acquire them. Do not read this book in sequence, allow yourself to jump around. Following chapter one, all chapters and some sections will list prerequisites. Some of these will be other sections, some will be topics you should already know and are summarized in the appendices, and some will be techniques that are too esoteric for the primary thrust of the book and are also in the appendices. You should read actively and ask yourself questions and try to answer them. Work the exercises, problems, and projects that interest you. Those marked with an * are considered to be very important. I recommend doing one project for every Part of the Book.

The fundamental ideas of classical physics are intuitively known to us, but explaining them is difficult. Explicitly performing the calculations we make intuitively can be enormously difficult. One task of this book is to give you the tools to make such calculations.

The first topic to study is that of motion, what we call *classical mechanics*. This begins with the tools to describe motion, including elementary calculus—the mathematics that allows us to represent changes. We will then turn to the causes of motion. After examining several cases of how classical mechanics can predict motions, we will abstract these cases to the laws of *conservation*—these laws specify that certain quantities do not change within a closed system.

What is a closed system? A closed system is a bit of a haphazard thing at this point. For now we can think of it as a system where nothing of importance to us enters it or leaves it.

The beginning of what we think of as physics was the work of the great physicists Galileo Galilei, Johannes Kepler, and Sir Isaac Newton. Kepler took the astronomical observations of Tycho Brahe and analyzed them to determine the laws that govern the motion of the planets around the Sun—called Kepler's laws. Galileo performed experiments that established the properties of falling bodies and the principle that unless you push on it some way, an object will travel in a straight line and at constant speed (the law of inertia).

Newton wrote out the principles of classical mechanics, optics, and gravitation. This laid the groundwork for rapid progress in classical mechanics. This became a program in its own right.

The program was to derive, one way or another, a force law. A force is understood to be something that pushes or pulls. A force law is then some way of mathematically describing a specific force. Once you had a force law you could use Newton's laws of motion to derive an equation describing the changing states of motion—what we call a differential equation. Once this equation is solved, then you can predict all future motion of the system you are studying.

Following this program, progress was rapid! Newton only identified a single force law in his work, that was the force of gravity. This technique allowed him to derive Kepler's laws mathematically. It also allowed him to discover the first known unification of the laws of physics. He equated the fall of an apple with the fall of the Moon around the Earth. The Moon falls around the Earth? Yes, it does, and we will get to that in time. Newton's laws of motion predict a whole host of phenomena, they are very powerful! In fact for a long time it was thought that his laws were so powerful that the term *mechanical universe* was developed to describe the entire world, and it was believed that Newtonian mechanics led the way to its description.

James Joule made the next significant discovery, that of energy. He learned that there is a quantity, just a number, that is related to force, that we call energy. It turns out that if we determine this quantity at one time, then no matter what we do the number will not change. This is called the *conservation of energy*. Folowing this a whole new branch of physics was invented to describe the effects of energy, and the nature of energy within matter. This is called *thermodynamics* and its immediate application was the first accurate description of heat.

At the same time experiments were being done that unlocked some of the principles of electricity. Magnetism had been studied since the Middle Ages. Hans Oersted and Thomas Faraday discovered the laws that connected electricity and magnetism; namely that electricty in a coil around an iron rod induces magnetism in the rod, while moving a magnet through a coil of wire induces electricity in the wire.

It fell to James Maxwell to make the second great unification of physics. He found the equations that linked electricity, magnetism, and light. This unification forged the connection that made electricity, magnetism, and light different aspects of the same thing. That light waves were the device that propagates the electric and magnetic fields through a substance that did not react with anything, called the luminiferous ether. This was a great theory! It explained many things, and made many predicitions. It established the wave theory of light and led to many applications including radio.