1.10 The development of quantum mechanics

In 1900 Max Planck discovered a formula that describes the blackbody radiation curve (see Figure 1). He did this first by taking the measured points and forcing a curve to fit those points (a process called curve fitting that leads to a kind of formula based directly on observation or experimental results, an *empirical formula*). Once he had the empirical formula he proved rigorously that it was correct. There was only one problem with his results, he didn't like them. Why didn't he like them? Because the only way to produce the curve was to force the energy that produced it into discrete chunks.

What is so bad about discrete chucks? In fact, what does it mean to have energy in discrete chunks? To cover this we need to go back into history. A long time ago, back with the ancient Greeks we knew only the counting numbers, what we call *natural numbers*. A world with only natural numbers is a jagged world of boxes. We see smooth curves most of the time, between any two points on a smooth curve we can always add another point. This is a property of the real numbers. Distances and most other quantities of the physical world in classical physics are smooth, what we call continuous. Natural numbers are discrete, real numbers are continuous. The discovery that the only way to produce the nice continuous curve of Figure 1 is the requirement that light energy comes in discrete chucks was quite a blow! Planck came up with a name for the chunks of light, *quanta*.

This was a nice idea, but few people believed it. After all, a model must make a prediction; what predictions did this new idea make? Albert Einstein, in the year that he discovered special relativity, also explained a puzzling phenomen using the new quantum theory. In the same year he also proved the existence of atoms and explained the curious jiggling motion discovered by Brown, called Brownian motion. The phenomen he explained using quantum theory was one where shining unltraviolet light onto a sheet of metal causes an electric current to occur in discrete jumps of current. This is called the *photoelectric effect*. Einstein explained that quanta of light, now called *photons*, impact the metal and force an electron to move from one atom to a nearby atom, thus creating a moving charge—a *current*.

Many puzzling effects and ideas came out, and the result was the new model of the atom based discrete levels of energy for different atoms. Many people have a solar system-like atom with the nucleus at its center and electrons orbiting like planets. This model has created many misunderstandings among writers suggesting that atoms could actually be miniature solar systems, leading to infinite regressions of levels of reality. In reality, the best way to think of it is a set of nested shells of indeterminate thickness, into which there are an integer number of electrons somewhere in the shell. The specific locations of the electrons are uncertain. Niels Bohr developed a model that was correct for Hydrogen, but there were problems with other atoms. It took the combined efforts of many famous physicists to figure out the physics of the quantum world. Werner Heisenberg developed a highly abstract theory that seemed to be correct. Erwin Schrödinger developed a less abstract theory that was based on a wave equation. Paul Dirac showed that the two approaches are, in fact, equivalent. Thus was born quantum mechanics.