2.1 Historical Background

Towards the end of the 1800s physics had well-established theories of mechanics, heat, light, electricity, magnetism, and gravity, and there were not that many things that people didn't have an explanation for. The unexplored parts of physics left were the extremes - the very small, the very large, the very hot, etc, and there was no reason to believe that the established laws of physics wouldn't work in those conditions. In the realm of the very small, physicists had started splitting atoms. The direct proof of the existence of subatomic particles came from the discovery of electron by J. J. Thompson who in 1899 showed that cathode rays were made up of negatively charged particles which were 2000 times lighter than the lightest atom.

The question arose as to how an atom is held together if positive and negative charges were to be so near each other. If electrons were going around the heavier nuclei just as planets go around the Sun, electron would have to be accelerating. But Maxwell's equations for electricity and magnetism had an unambiguous perdition that accelerating charges would radiate energy away in the form of electromagnetic waves. Therefore, the electrons in atoms should lose energy and plunge into the nucleus. Clearly this does not happen and atoms are somehow stable. This was a major problem with classical physics.

But, it was the explanation of the black-body spectrum by Max Planck that really shook the foundation of physics since it introduced radically new possibilities in physics. The black-body spectrum is the distribution of energy among electromagnetic waves of various wavelengths emitted from a hot body such as an oven at a particular temperature. In 1900 Max Planck put forth a theoretical explanation of the black body spectrum based on a quantization hypothesis. Planck showed that one can explain all aspects of the black-body spectrum if one were to assume that the energy exchanged between the walls of the cavity and the electromagnetic waves was an integral multiple of a fundamental quantum of energy, which he identified as hf, where f is the frequency of the electromagnetic wave in the cavity and h a constant, which is now called the Planck constant.

There were other unexplained phenomena at the time that contributed to the revolution in physics in the early 1900s. We will study two of them in this book. One unexplained phenomenon was the photo-electric effect which we will study in this chapter. Briefly, when you shine light of different frequencies on a metal, you find that if the frequency of light is above a critical frequency electrons are ejected from the metal. Of particular surprise was the fact that no electron was ejected if light shone had a frequency lower than the critical frequency regardless of intensity of the light. Other surprises in the photoelectric phenomena involved the energy of the most energetic electron emitted for the surface. That energy did not depend on the intensity of light but varied linearly with the frequency of light. Classical theory failed to give an explanation of these observations. Einstein's explanation of the phenomenon in 1905, to be described below, and Millikan's experiments confirming the predictions of Einstein's theory convinced many people of the fundamental quantum nature of light although some physicists remained skeptical.

The next great experiment providing additional support of the idea of quantized nature of light came from Arthur Compton. Compton's explanation of the effect convinced many more people that light indeed consisted of photons which acted as particles with well-defined energy and momentum. Now, light appeared to have a dual character: it behaved as waves in some experiments and as particles in some other experiments.

The other unexplained phenomenon we will study in this book concerns the emission spectra of atoms. When a tube filled with a gas is electrically discharged, it gives out light whose spectrum is called the emission spectrum of the gas. It was found that the light coming out of the discharging of atomic gases had discrete wavelengths, i.e., the emission spectrum was discrete. We will study this in more detail in the next chapter. In 1913 Neils Bohr put forth a quantum hypothesis, called the Bohr model, in which electrons in atoms moved in stable orbits around the nucleus and gave out light when they jumped from one orbit to another. The hypothesis of stable orbits violated classical physics of electricity and magnetism, but it was needed to explain the discrete nature of the emission spectrum. The hypothesis explained the emission spectrum of Hydrogen atoms well but lacked fundamental reason for the hypothesis.

If light can have both wave and particle aspects, can electron have wave aspects also? In 1924 Louis de Broglie introduced the idea of matter waves that he used to assign wavelengths to electrons when in an orbit around the nucleus. Using the wave properties of electron de Broglie was successful in explaining Hydrogen spectrum which lent support to his hypothesis and provided justification for the stability of Bohr orbits.

The search to describe matter as waves led to the discovery of wave mechanics by Erwin Schrödinger in 1926, which successfully explained the discrete nature of the Hydrogen spectrum. Before the discovery of wave mechanics, in 1925 Werner Heisenberg had introduced matrix mechanics which gave rules for how the observables such as energy, momentum, and position of electrons may evolve in time when in an atom, and had successfully produced the Hydrogen spectrum. Now, we know that both matrix mechanics and wave mechanics are different formulations of the same principles of mechanics, which is called the quantum mechanics.