

2.1: Prelude to the Foundations of Quantum Mechanics

The concepts of quantum mechanics were invented to explain experimental observations that otherwise were totally inexplicable. This period of invention extended from 1900 when Max Planck introduced the revolutionary concept of quantization to 1925 when Erwin Schrödinger and Werner Heisenberg independently introduced two mathematically different but equivalent formulations of a general quantum mechanical theory. The Heisenberg method uses properties of matrices, while the Schrödinger method involves partial differential equations. We will develop and utilize Schrödinger's approach because students usually are more familiar with elementary calculus than with matrix algebra, and because this approach provides direct insight into charge distributions in molecules, which are of prime interest in chemistry.

Heisenberg and Schrödinger were inspired by four key experimental observations: the spectral distribution of black-body radiation, the characteristics of the photoelectric effect, the Compton effect, and the luminescence spectrum of the hydrogen atom. Explanation of these phenomena required the introduction of two revolutionary concepts:

1. physical quantities previously thought to be continuously variable, such as energy and momentum, are quantized, and
2. momentum, p , and wavelength, λ , are related, $p = \frac{h}{\lambda}$, where h is a fundamental constant.

We will use a quasi-historical approach in this chapter to emphasize that individuals created knowledge by inventing new ideas or concepts. What is not apparent here is that these new ideas initially were greeted with considerable skepticism, and acceptance was slow because of counter proposals that were not so revolutionary. Only after some time did inconsistencies in the counter proposals become apparent. By "quantized," we mean that only certain values are possible or allowed. For example, money is quantized. Money does not come in continuous denominations. In the United States the smallest unit of money is a penny, and everything costs some integer multiple of a penny.

From high school and freshman physics, as well as from everyday experience, we learn that particles have momentum, which is mass times velocity. Although more abstract, the wave properties of light are clearly demonstrated by interference, diffraction and refraction effects. That a relationship between momentum (a particle property) and wavelength (a wave property) applies to both particles and light was, and remains, somewhat amazing and revolutionary. This relationship, called the "wave-particle duality," means that particles have wave-like properties and light waves have particle-like properties.

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