CHAPTER 20

An Introduction to the Methods of Quantum Mechanics

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20.1 INTRODUCTION

So far, we have discussed some of the experimental evidence that led to the breakdown of classical physics and to the beginning of quantum mechanics. We have seen how the introduction of the quantization postulates explained the experimental facts concerning blackbody radiation, the photoelectric effect, and the hydrogen spectrum. These theories constitute what we call today the old quantum theory (OQT).

Despite its successes, the OQT has some serious deficiencies:

1. The theory can be applied only to periodic systems (harmonic oscillators, circular motion, and such), although there are many important physical systems that are not periodic.

2. Although the Bohr theory predicts the observed wavelengths of the spectrum of hydrogen, it does not explain why certain wavelengths are more intense than others; that is, it does not account for the rate of transition between different energy levels.

3. The Bohr theory explains well the spectrum of monatomic hydrogen (H), singly ionized helium (He⁺), and reasonably well those of the alkali elements (lithium Li, sodium Na, potassium K, . . . ), but only because these are H-like atoms (as will be shown in Chapter 21). It fails to explain the spectrum of even the simplest of the multielectron atoms, He.

4. But perhaps the most serious criticism of the OQT is that it is intellectually unsatisfying; it is not a unified or a general theory. It assigns to microscopic particles a well-defined path that, by the uncertainty principle, is not possible.

20.2 THE SCHRODINGER THEORY OF QUANTUM MECHANICS

20.2a The Time-dependent Schrödinger Equation

The basis of the modern theory of quantum mechanics was developed in 1925 by Erwin Schrödinger (1887–1961); an equivalent, but mathematically different, theory was presented just about the same time by Werner Heisenberg. In this book we will deal only with the Schrödinger theory.

The most important fact that we have presented so far is that the behavior of a microscopic particle is governed by the wave associated with it. In trying to find the wave associated with the particle, de Broglie’s postulates give us the first guideline. We have seen that if a particle has a well-defined momentum and energy, we can use a sinusoidal traveling wave, that is, either

\[ \psi = A \sin (kx - \omega t) \quad \text{or} \quad \psi = A \cos (kx - \omega t) \]

or a linear combination of both. As we have seen, if we want to describe a free particle, which is partially localized, we could use a wave packet.