



FIGURE 10 Diffraction patterns produced by (a) a beam of electrons passed through a substance and (b) a beam of visible light passed through a tiny aperture. Each pattern shows the results of bent waves that have interfered with each other. The bright areas correspond to areas of increased energy, while the dark areas correspond to areas of decreased energy.

The Heisenberg Uncertainty Principle

The idea of electrons having a dual wave-particle nature troubled scientists. If electrons are both particles and waves, then where are they in the atom? To answer this question, it is important to consider a proposal first made in 1927 by the German theoretical physicist Werner Heisenberg.

Heisenberg's idea involved the detection of electrons. Electrons are detected by their interaction with photons. Because photons have about the same energy as electrons, any attempt to locate a specific electron with a photon knocks the electron off its course. As a result, there is always a basic uncertainty in trying to locate an electron (or any other particle). *The Heisenberg uncertainty principle states that it is impossible to determine simultaneously both the position and velocity of an electron or any other particle.* Although it was difficult for scientists to accept this fact at the time, it has proven to be one of the fundamental principles of our present understanding of light and matter.

The Schrödinger Wave Equation

In 1926, the Austrian physicist Erwin Schrödinger used the hypothesis that electrons have a dual wave-particle nature to develop an equation that treated electrons in atoms as waves. Unlike Bohr's theory, which assumed quantization as a fact, quantization of electron energies was a natural outcome of Schrödinger's equation. Only waves of specific energies, and therefore frequencies, provided solutions to the equation. Together with the Heisenberg uncertainty principle, the Schrödinger wave equation laid the foundation for modern quantum theory. *Quantum theory describes mathematically the wave properties of electrons and other very small particles.*