Thus, all forms of electromagnetic radiation can be described from two points of view. At one extreme, the electromagnetic wave description suits the overall interference pattern formed by a large number of photons. At the other extreme, the particle description is more suitable for dealing with highly energetic photons of very short wavelengths.

MATTER WAVES

In the world around us, we are accustomed to regarding things such as thrown baseballs solely as particles, and things such as sound waves solely as forms of wave motion. As already noted, this rigid distinction cannot be made with light, which has both wave and particle characteristics. In 1924, the French physicist Louis de Broglie (1892–1987) extended the wave-particle duality. In his doctoral dissertation, de Broglie proposed that all forms of matter may have both wave properties and particle properties. At that time, this was a highly revolutionary idea with no experimental support. Now, however, scientists accept the concept of matter's dual nature.

Did you know?

Louis de Broglie's doctoral thesis about the wave nature of matter was so radical and speculative that his professors were uncertain about whether they should accept it. They resolved the issue by asking Einstein to read the paper. Einstein gave his approval, and de Broglie's paper was accepted. Five years after his thesis was accepted, de Broglie won the Nobel Prize for his theory.

The wavelength of a photon is equal to Planck's constant (h) divided by the photon's momentum (p). De Broglie speculated that this relationship might also hold for matter waves, as follows:

WAVELENGTH OF MATTER WAVES

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$\textbf{de Broglie wavelength} = \frac{\textbf{Planck's constant}}{\textbf{momentum}}$$

As seen by this equation, the larger the momentum of an object, the smaller its wavelength. In an analogy with photons, de Broglie postulated that the frequency of a matter wave can be found with Planck's equation as illustrated below:

ADVANCED TOPICS

See "De Broglie Waves" in **Appendix J: Advanced Topics** to learn more about matter waves.

FREQUENCY OF MATTER WAVES

$$f = \frac{E}{h}$$

$$\textbf{de Broglie frequency} = \frac{\textbf{energy}}{\textbf{Planck's constant}}$$

The dual nature of matter suggested by de Broglie is quite apparent in these two equations, both of which contain particle concepts (E and mv) and wave concepts (λ and f).