16.5: Wave-Particle Duality

Einstein had shown that the momentum of a photon is

$$p = \frac{h}{\lambda}. \tag{16.5.1}$$

This can be easily shown as follows. Assuming $E = h\nu$ for a photon and $\lambda\nu = c$ for an electromagnetic wave, we obtain

$$E = \frac{hc}{\lambda} \tag{16.5.2}$$

Now we use Einstein's relativity result, $E = mc^2$, and the definition of mementum $p = mc$, to find:

$$\lambda = \frac{h}{p}, \tag{16.5.3}$$

which is equivalent to Equation 16.5.1. Note that m refers to the relativistic mass, not the rest mass, since the rest mass of a photon is zero. Since light can behave both as a wave (it can be diffracted, and it has a wavelength), and as a particle (it contains packets of energy $h\nu$), de Broglie reasoned in 1924 that matter also can exhibit this wave-particle duality. He further reasoned that matter would obey the same Equation 16.5.3 as light. In 1927, Davisson and Germer observed diffraction patterns by bombarding metals with electrons, confirming de Broglie's proposition.[1]

Rewriting the previous equations in terms of the wave vector, $k = \frac{2\pi}{\lambda}$, and the angular frequency, $\omega = 2\pi\nu$, we obtain the following two equations

$$\begin{aligned} p &= \hbar k \\ E &= \hbar\omega, \end{aligned}$$

which are known as **de Broglie's equations**. We will use those equation to develop wave mechanics in the next chapters.

1. The previous 3 sections were adapted in part from Prof. C. David Sherrill's A Brief Review of Elementary Quantum Chemistry Notes available here.