7.3: Meaning of Quantum Wave Function

Bragg diffraction illustrates the most difficult thing to understand about quantum mechanics, namely that particles can have wave-like properties and waves can have particle-like properties.

The variation of X-ray intensity with angle seen in a Bragg diffraction apparatus is very difficult to explain in any terms other than wave interference. Yet, X-rays are typically detected by a device such as a Geiger counter which produces a pulse of electricity for each X-ray particle, or photon, which hits it. Thus, X-rays sometimes act like particles and sometimes like waves.

Light isn't alone in having both particle and wave properties. Davisson and Germer and later G. P. Thomson (son of J. J. Thomson, the discoverer of the electron) showed that electrons also can act like waves. They did this by demonstrating that electrons undergo Bragg diffraction in crystals, much as X-rays do.

Most physicists (including Albert Einstein) have found quantum mechanics to be extremely bizarre, so if you feel the same way, you are in good company! However, there is a useful interpretation of quantum mechanics which at least allows us to get on with using it to solve problems, even though it may not satisfy our intuitive reservations about the theory.

The displacement of the matter wave associated with a particle is usually called the wave function, Ψ. It is not at all clear what Ψ is a displacement of, but its use is straightforward. The absolute square of the wave function, $|\Psi(x,t)|^2$, is proportional to the probability of finding the associated particle at position x and time t. The absolute square is taken because under many circumstances the wave function is actually complex, i. e., it has both real and imaginary parts. The reasons for this will be discussed later.

Due to the interpretation of the wave function, quantum mechanics is a probabilistic theory. It does not tell us with certainty what happens to a particular particle. Instead, it tells us the probability for detecting the particle in any given location. If many experiments are done, with one particle per experiment, the numbers of experiments with particles being detected in the various possible locations are in proportion to the quantum mechanical probabilities.