Quantum Mechanics-Section14

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1 The wave-particle dualism

Let us analyze a diffraction experiment to see how the mutual association of two aspects, whether of matter or of radiation is to be understood. To be specific, if we think of the experiments by G P Thomson we see that the electron diffraction photographs are identical with the Laue and Debye-Scherrer x-ray diffraction patterns. In electron as well as x-ray diffraction the observed pattern is precisely what one would expect on the basis of wave theory assuming the incident beam to be a harmonic wave and the intensity at any point of the pattern to be proportional to the absolute square of the amplitude of the wave at that point.

It is also an empirical fact that the nature of the diffraction pattern is quite independent of the incident beam intensity i.e. on taking a long exposure diffraction photograph with a weak incident beam one gets exactly the same pattern as with a beam many time more intense and a correspondingly shorter exposure. This is again what one would expect on the basis of wave theory. It acquires profound significance when we recall that the beam actually consists of discrete particles (electrons or photons). For it implies that the diffraction process is independent of the number of particles simultaneously present in the beam , and hence that the wave theory manifested through diffraction is not the result of some conspiracy among the particles present. Instead, the wave nature is the inherent property of each particle. This inference is confirmed by experiments in which the beam intensity is made so low that there is effectively only one particle at a time going through the apparatus, the diffraction pattern still emerges if recording is made for sufficiently long period of time. We have to conclude therefore that associated to each particle there exists a wave that diffracts through the crystal.

If the wave is represented by a time dependent function $\psi(x,t)$, diffraction manifests itself in a variation of $|\psi|^2$ with x at points along the surface of the photographic film. The form of $|\psi|^2$ as a function of x is same for all the particles, and it is the accumulated effect of all of them which makes up the actually observed diffraction pattern. The intensity distribution $I(x)$ in the diffraction photograph is then proportional to $|\psi|^2$.

The conceptual picture of the diffraction phenomenon still leaves us with the following questions. Does the electron (or photon) smear itself out over the photographic plate in a manner determined by its own wave function ? The answer is no. It remains discrete and may be detected as a discrete particle at some point of the diffraction pattern. In that case, how can the photographic plate possibly know of the existence of peaks and zeros of $|\psi|^2$? The only possible seems to be the statistical one. Each individual particle is recorded at some point or other of the photographic plate, at random, with a probability proportional to the value of $|\psi|^2$ at that point. When a large number of particles are recorded in this fashion the average number arriving in the neighbourhood of a particular point x of the photograhic plate is proportional to $|\psi|^2$, on the other hand, the intensity $I(x)$ of the diffraction pattern is also proportional to this average number. Hence, $I(x) \propto |\psi|^2$, and thus the formation of the diffraction pattern through the diffraction of individual particles is explained.

The statistical interpretation is the fundamental feature of wave mechanics. Every particle has a wave function associated with it . The wave function determines the corpuscular characteristics like position, momentum and angular momentum *etc.* in a statistical sense. For example, a particle with wave function $\psi(x,t)$ has a probability proportional to $|\psi(x,t)|^2$ for being found in the neighbourhood of the point x.

References

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[1] Figures are collected from online resources.