Born's Statistical Interpretation

Shortly after quantum theory was developed with the matrix mechanics of Heisenberg in 1925 and the wave mechanics of Schrödinger in 1926, it was often not clear how to describe even the simplest experiments and how to distinguish space-time and quanta in these situations. As seen in Figure 5.8, the tracks left by quanta within a cloud chamber, a device filled with supersaturated vapor which creates an ionized trail in response to a charged particle, do not seem so different than the time-like trajectories of any massive particle within a light-cone of space-time. This was discussed at the 1927 Solvay Conference, which was dominated by discussion of the recently discovered formulations of quantum mechanics. Max Born (1882-1970), who had proposed his rule for the statistical interpretation of quantum mechanics, raised that very question as prompted by a concern of Einstein's [4, pp. 160, 437]:

> *Mr. Einstein has considered the following problem: A radioactive sample emits α-particles in all directions; these are made visible by the method of the Wilson cloud [chamber]. Now, if one associates a spherical wave with each emission process, how can one understand that the track of each α-particle appears as a (very nearly) straight line? In other words: how can the corpuscular character of the phenomenon be reconciled here with the representation by waves?*
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> G. Bacciagaluppi and A. Valentini, Quantum Theory at the Crossroads: Reconsidering the 1927 Solvay Conference, Cambridge University Press, 2013.

Born goes on to say

> *The description of the emission by a spherical wave is valid only for as long as one does not observe ionization.*
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> G. Bacciagaluppi and A. Valentini, Quantum Theory at the Crossroads: Reconsidering the 1927 Solvay Conference, Cambridge University Press, 2013

In other words, Born appeals to observation or measurement as the crucial factor and he follows this by referring to both Heisenberg's "reduction of the wave-packet" as well as an attempted unitary description of measurement by Pauli.

In Heisenberg's uncertainty paper, he also acknowledges in a footnote, "The statistical interpretation of the de Broglie waves was first formulated by Einstein.", and "It was mathematically analyzed in a fundamental paper of M. Born and used for the interpretation of collision phenomena." [7] Heisenberg cites Einstein's second paper from 1925, *Quantum Theory of the Monatomic Ideal Gas*, the first application to such a gas of what now is called *Bose-Einstein statistics*. In this paper, Einstein again applies his fluctuation techniques to a volume of molecules in the gas and arrives at two terms of a wave-particle duality, one corresponding to a particle fluctuation and the other due to interference of waves, similar to his 1909 result which had exhibited a special case of wave-particle duality for photons as discussed in the section *The Fall of Classicality*. Einstein's citations of de Broglie's 1924 thesis, sent to him by his adviser Paul Langevin, brought wide notice to de Broglie's work. In Section 9 of this paper, Einstein remarks on the diffraction of a stream of gas molecules by a slit (similar to de Broglie): "Large diffraction angles occur if λ is of the same order of magnitude as σ or larger. Thus, in addition to deflections due to collision in accord with mechanics, mechanically inexplicable deflections of the molecules also will occur with frequency comparable to the former, which will diminish the mean free path." These conclusions are very close to Born's statistical interpretation.

Born's paper was the first to contain the probability concept within the full theory of quantum mechanics developed independently by Heisenberg in 1925 and Schrödinger in 1926. Born writes: "One obtains the answer to the question, not *what is the state after the collision* but *how probable is given the effect of the collision*." Max Born was awarded the Nobel Prize for his fundamental research in quantum mechanics, especially for his statistical interpretation of the wave-function, but not until 1954, long after his 1926 contribution, suggesting the continuing resistance to the view that nondeterminism is a fundamental property.